AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852

TRANSACTIONS.

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No. 872.

THE ALBANY WATER FILTRATION PLANT.

By ALLEN HAZEN, Assoc. M. Am. Soc. C. E.

PRESENTED JANUARY 3D, 1900.

WITH DISCUSSION.

HISTORICAL.

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Some of the city sewers enter the river above the intake, but most of them are below it. In times of flood, the water thus obtained was polluted by the sewage of only a few of the city sewers. At low-water stages, however, owing to the tidal currents, the water con-

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Some of the city sewers enter the river above the intake, but most of them are below it. In times of flood, the water thus obtained was polluted by the sewage of only a few of the city sewers. At low-water stages, however, owing to the tidal currents, the water con-

tained much sewage, which was carried up stream to the intake, and the sewage of the city was thus present, in very considerable amount, in its own water supply.

In addition to the local sources of pollution, the river received the sewage of Troy and the surrounding cities, 7 or 8 miles above, and the sewage of Schenectady, Utica, Rome, and many other places farther away.

Under these conditions the typhoid fever death rate in Albany was excessive. Professor W. P. Mason, of Troy, made a report upon the quality of the water to the Water Board in 1885, in which he stated in unmistakable terms that the water as then used was a source of disease, and should be abandoned at the earliest practicable date.

Following this, an attempt was made to secure a ground-water supply, but without results. Studies were then made for gravity sources of supply, mentioned in the reports of the Board of Water Commissioners for the years 1891 to 1893.

Failing to secure the necessary legislation to introduce a gravity supply, the Board, in 1896, investigated methods of purifying the present supply. The matter was studied by the Board and by its Superintendent, George I. Bailey, M. Am. Soc. C. E., and the writer was engaged, in January, 1897, to examine the studies which had been made, and to report upon the projects presented. This report, presented to the Board in February, 1897, recommended the general scheme previously outlined by the Superintendent, namely, to abandon the present intake, and to establish a new one at a point about two miles farther up the river, at a point above all the local sources of pollution, and to pump the water by low-lift pumps to a settling basin, from which it would flow to sand filters, and thence through a pure-water conduit to the present pumping station in Quackenbush Street.

Among other considerations, taken into account in determining upon this site, was the fact that the present high-service reservoir is not at a sufficient elevation to supply properly the highest parts of the city, although it is on the highest ground in its immediate neighborhood. It will be necessary ultimately to construct a new high-service reservoir, and the most available location for it is upon land about $1\frac{1}{2}$ miles northeast of the present Prospect Hill Reservoir, where there is an excellent site directly back of that recommended for the filters; so that when it becomes necessary to construct the reservoir,

the most advantageous location for a pumping station to supply it will be close to the filters.

The report was accepted, the recommendations adopted, and the necessary funds were provided; and, in July, 1897, the preparation of plans was begun.

As the pure-water conduit was to be placed in the Erie Canal, and as the work of constructing it necessarily had to be done during the season of closed navigation, plans for this part of the work were prepared first. The contract was let to Messrs. Hilt, Johnson, Fitzgerald & Mulderry in November, 1897, and that part of the work under the canal was completed before navigation opened, May 1st, 1898.

Plans for the filters and sedimentation basin were completed in January, 1898, and the contract was awarded in February to Messrs. T. Henry Dumary and the Wilson and Baillie Manufacturing Company, who commenced work under their contract in April; but, owing to various reasons connected with the installation of a very elaborate contractors' plant, work was not pushed actively by them until August, 1898. Contracts for the pumping machinery, and for the pumping station and intake, were let to the Prindle Pump Company and to Stone & Thurston, respectively, in June and August, 1898, and the work was carried out during the fall and winter. Gates and all special valves were furnished by the Eddy Valve Company. The work was sufficiently advanced so that a part of the plant was put in operation on July 27th, 1899. The old intake was closed on September 6th, 1899, since which time no unfiltered river water has been pumped to the city.

Source of Supply.

The Hudson River, at the point of intake, has a drainage area of 8 240 square miles. Of this, 4 570 square miles are tributary to the Hudson above Troy, 3 502 are tributary to the Mohawk, and 168 are tributary to the Hudson below the Mohawk.

The average annual flow of the streams probably amounts to at least 1 000 000 galls. per square mile per day, or over 8 000 000 000 galls. per day. The minimum flow is only a small fraction of this amount. No gaugings of the river at this point are available. George W. Rafter, M. Am. Soc. C. E., has made a study* of the flow of the Upper Hudson, and estimates the minimum flow at Mechanicsville at

* Report of the State Engineer and Surveyor for 1895, p. 119.

0.24 cu. ft. per second per square mile of tributary drainage area. Assuming that this figure applies to the whole of the Hudson above Troy, and taking a somewhat lower figure, namely, 0.15 cu. ft. per second per square mile, for the discharge of the Mohawk and of the Hud-

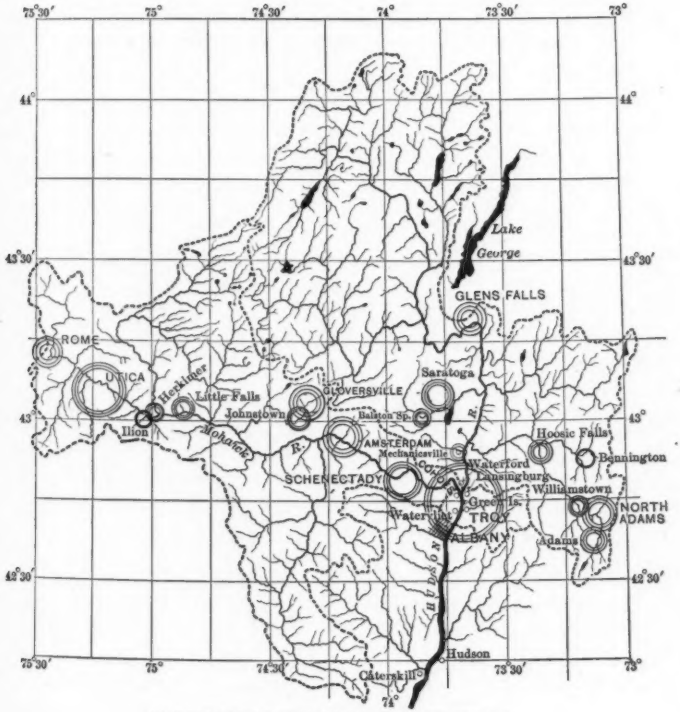


FIG. 1.

son below Troy, we arrive at a minimum flow of the Hudson at Albany of 1 647 cu. ft. per second, or 1 060 000 000 galls. per 24 hours, being, in round numbers, 100 times the average amount of water now taken from the river for water-works purposes, and at least 50 times the maximum.

Pollution of the Raw Water.—Table No. 1 gives the names of the cities and larger towns upon the river above the intake, with estimated populations and distances. The largest of these places are also shown upon the map of the water-shed, Fig. 1.

TABLE No. 1.—CITIES, TOWNS AND VILLAGES ON THE WATER-SHED OF THE HUDSON RIVER ABOVE ALBANY, WITH POPULATIONS OF 1 000 AND OVER.

Place.	County.	Approximate distance above intake. Miles.	Population in:		
			1880.	1890.	1900. (Estimated.)
Troy	Rensselaer	4	56 747	60 956	65 470
Watervliet	Albany	4	8 820	12 967	19 040
Green Island	Albany	5	4 160	4 463	4 788
Cohoes	Albany	8	19 416	22 509	26 450
Lansingburg	Rensselaer	8	7 432	10 550	14 980
Waterford	Saratoga	9	(1 822)	1 822	(1 822)
Mechanicsville	Saratoga	19	1 265	2 679	5 358
Schaghticoke	Rensselaer	27	(1 258)	1 258	(1 258)
Schenectady	Schenectady	28	13 655	19 002	26 450
Schuylerville	Saratoga	32	1 617	1 387	1 190
Greenwich	Washington	39	1 251	1 663	2 247
Fort Edward	Washington	43	4 080	4 424	4 182
Hoosic Falls	Rensselaer	44	4 530	7 014	10 860
Amsterdam	Montgomery	44	9 466	17 336	31 730
Cambridge	Washington	45	1 482	1 598	1 723
Sandy Hill	Washington	46	2 487	2 895	3 371
Glens Falls	Warren	49	4 900	9 509	18 450
South Glens Falls	Saratoga	49	1 083	1 606	2 387
Saratoga Springs	Saratoga	51	8 421	11 975	17 010
Ballston Springs	Saratoga	51	3 011	3 527	4 131
Fultonville	Montgomery	54	881	1 122	1 429
Fonda	Montgomery	54	944	1 190	1 500
Johnstown	Fulton	56	5 013	7 768	12 040
Bennington, Vt.	Bennington	56	(3 971)	3 971	(3 971)
Gloversville	Fulton	58	7 123	13 864	26 930
Canajoharie	Montgomery	63	2 013	2 089	2 168
Williamstown, Mass.	Berkshire	63	3 394	4 221	5 250
Corinth	Saratoga	64	510	1 222	2 444
North Adams, Mass.	Berkshire	68	10 191	16 074	25 340
Luzerne	Warren	68	468	868	1 610
Schoharie	Schoharie	68	1 188	1 028	889
Fort Plain	Montgomery	69	2 443	2 864	3 358
Middleburg	Schoharie	73	1 123	1 139	1 155
St. Johnsville	Montgomery	74	1 072	1 263	1 488
Cobleskill	Schoharie	74	1 222	1 822	2 717
Adams, Mass.	Berkshire	75	5 591	9 213	15 181
Warrensburg	Warren	82	748	893	1 073
Little Falls	Herkimer	82	6 910	8 783	11 160
Herkimer	Herkimer	90	(1 353)	(1 353)	(1 353)
Mohawk	Herkimer	91	1 441	1 806	2 264
Ilion	Herkimer	93	3 711	4 057	4 436
Frankfort	Herkimer	95	1 085	2 291	4 582
Utica	Oneida	107	33 914	44 007	57 090
Whitesboro	Oneida	113	1 370	1 663	2 018
New York Mills	Oneida	114	(1 195)	1 195	(1 195)
New Hartford Mills	Oneida	117	710	912	1 171
Oriskany	Oneida	118	597	860	1 239
Clinton	Oneida	127	1 236	1 269	1 303
Rome	Oneida	127	12 194	14 991	18 430
Waterville	Oneida	133	(1 734)	1 734	(1 734)
Total, not including rural population			272 838	354 672	479 415
Per square mile			33	43	59
Rural population per square mile (in addition)			—	30	—

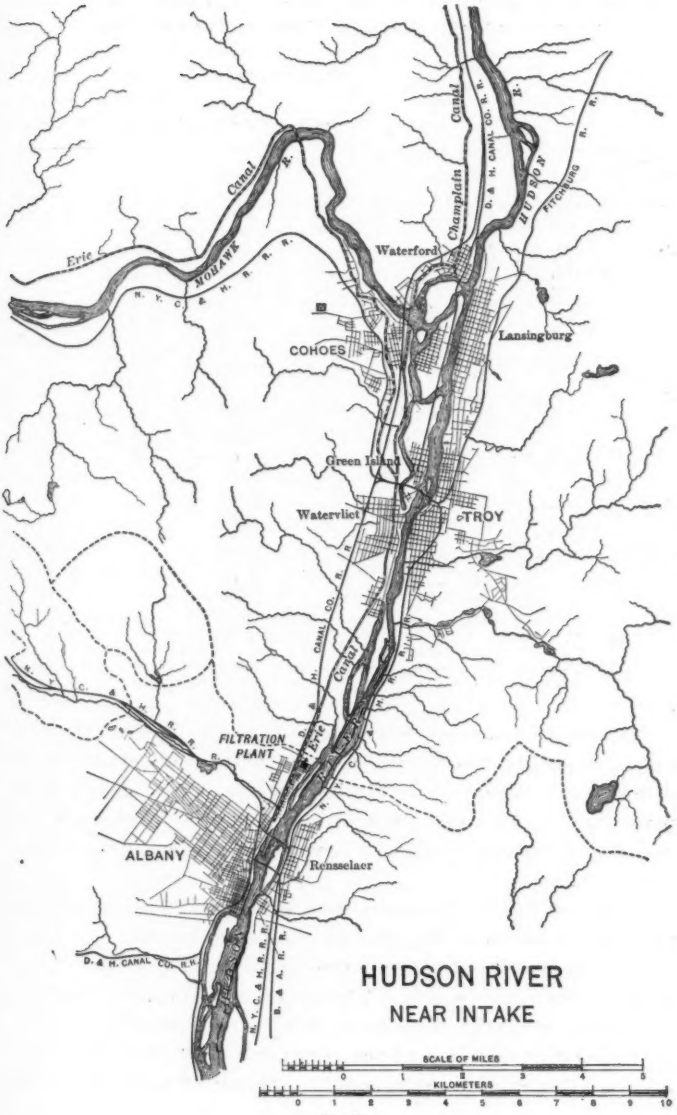

Erie Canal
Mohawk R.
N. Y. C. & H. R. R. R.
Champlain Canal
D. & H. CANAL CO. R. R.
Hudson R.
Fitchburg R. R.
Waterford
COHOES
Lansingburg
Green Island
Watervliet
TROY
Erie Canal
FILTRATION PLANT
ALBANY
Rensselaer
D. & H. CANAL CO. R.R.
B. & A. R. R.
HUDSON RIVER
NEAR INTAKE
SCALE OF MILES
0 1 2 3 4 5
KILOMETERS
0 1 2 3 4 5 6 7 8 9 10

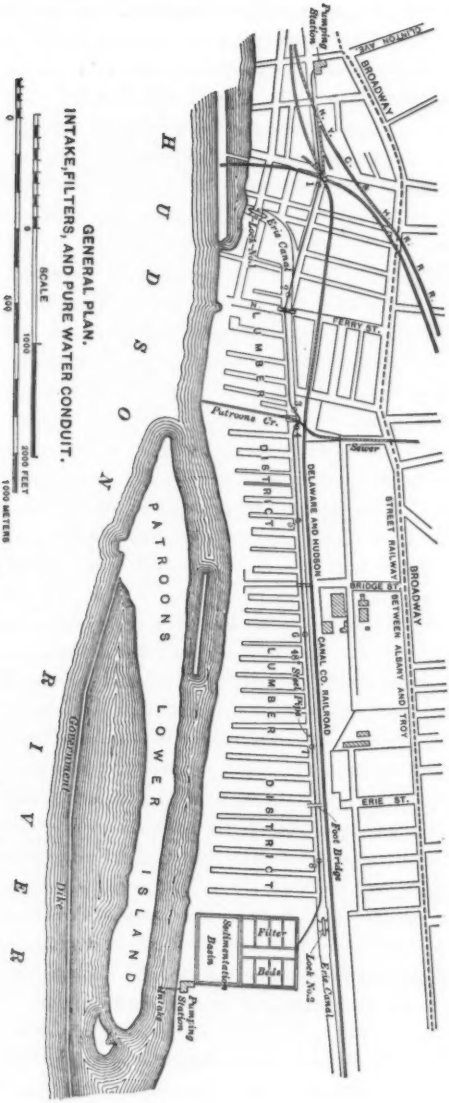
FIG. 2.

TABLE No. 2.—Bacterial Examinations of Water from Main Channel and from Back Channel at Proposed Points of Intake.

Date.	Hour.	Approximate state of tide.	Back Channel.		Main Channel.	
			Turbidity.	Bacteria.	Turbidity.	Bacteria.
1898.						
March 24..	3.00 P. M.	Low tide	.....	2 250	.....	.....
April 13..	11.00 A. M.	Rising	.....	1 927	.....	2 889
20..	7.15 A. M.	High	.....	1 970	.....	.....
20..	8.00 "	High	.....	.....	.....	2 165
June 8..	12.00 M.	High	0.04	400	.....	2 200
20..	1.30 P. M.	Falling	0.09	350	.....	825
24..	7.00 A. M.	Low	0.03	1 000	0.04	1 040
	9.20 "	Rising	0.03	760	0.04	1 120
	11.40 "	Nearly high	0.03	600	0.04	1 040
	2.00 P. M.	After high	0.03	300	0.04	4 000
	4.20 "	Falling	0.03	1 400	0.04	5 200
	6.40 "	Low	0.03	640	0.04	3 600
29..	2.00 P. M.	Nearly high	.....	.....	0.03	2 040
	2.30 "	High	0.04	860	.....	.....
July 7..	9.00 A. M.	High	.....	.....	0.03	4 360
	10.00 "	After high	0.04	560	.....	.....
13..	11.00 A. M.	Rising	.....	.....	0.03	16 780
	12.00 M.	Nearly high	0.03	17 926	.....	.....
21..	11.00 A. M.	Falling	.....	.....	0.03	13 759
	12.00 M.	Falling	0.04	18 724	.....	.....
29..	.....	.....	.....	13 759	.....	15 230
Aug. 4..	.....	.....	.....	20 200	.....	16 070
20..	.....	.....	.....	11 275	.....	7 280
27..	.....	.....	.....	17 286	.....	16 750
Sept. 2..	.....	.....	.....	12 744	.....	9 640
8..	.....	.....	.....	11 860	.....	11 289
13..	.....	.....	.....	14 700	.....	14 366
26..	.....	.....	.....	22 750	.....	17 280
Oct 1..	.....	.....	.....	19 760	.....	16 800
7..	.....	.....	.....	5 260	.....	3 724
21..	.....	.....	.....	9 700	.....	6 240
Nov. 4..	.....	.....	.....	.....	.....	3 560
9..	.....	.....	.....	.....	.....	8 760

Without entering into a detailed discussion, it may be said that the amount of sewage, with reference to the size of the river and the volume of flow, is a fraction less than that at Lawrence, Mass., where a filter plant has also been constructed, but the pollution is much greater than that of most American rivers from which municipal water supplies are taken.

Position of Intake.—The general form of the river channels near the new plant is shown in Figs. 2 and 3. Opposite the plant is a long, narrow island. The land upon which the filter plant is built fronts the back channel of the river. This back channel carried formerly a considerable proportion of the river's flow, but, to improve navigation, the United States Government has constructed a dike, the top of which is about 5 ft. above low water, and this dike cuts off most of the flow



GENERAL PLAN.
INTAKE, FILTERS, AND PURE WATER CONDUIT.

SCALE 0 600 1000 2000 FEET 1000 METERS

FIG. 3.

through this channel at ordinary river stages. At flood stages the dike is overtopped, and the channel takes a large amount of water.

The question arose as to whether to build an intake across the back channel and the island to the main channel of the river, or to take water from the more convenient back channel. Each point had its advantages. To determine the relative character of the water, examinations were made by Dr. George Blumer, of the Bender Hygienic Laboratory, of Albany. The most important of the results of these examinations are shown in Table No. 2.

The results, up to July 7th, are normal, and represent the condition of the water as it would be ordinarily. Afterward, commencing July 9th, the contractors dumped sand and gravel in the back channel, and took it up again by dredging, for construction purposes, with the result that this water was fouled, and the samples taken after that time do not represent its normal condition.

The results, up to July 7th, showed, in a general way, that the water in the back channel was considerably better than that in the main channel. Occasionally, there was but little difference, and this would always be the case when the river was in flood. At no time was the water in the back channel materially worse than in the main channel.

One of the city sewers enters the river at a point a short distance from the outlet of the back channel, and there was a possibility that sewage therefrom would be carried up the back channel by flood tides. On the other hand, the water in the main channel had come directly from the Troy sewers, while that in the back channel was more or less completely cut off from the main current, and was moved back and forth by the tides, and opportunities for natural purification were present in greater degree than in the main channel. These conditions, apparently, more than offset the possible admixture of fresh sewage.

The plan finally presented was to build two intakes independent of each other, one to each channel, and connected with the pumping station separately; but, in view of the superior average quality of the water in the back channel, up to the time of letting the contract for the intake, it was decided to construct at first only the intake in the back channel, and put in a stub for the other intake, the construction of which was to be deferred until such time as might seem necessary, or indefinitely, should the relative qualities of the raw water in the

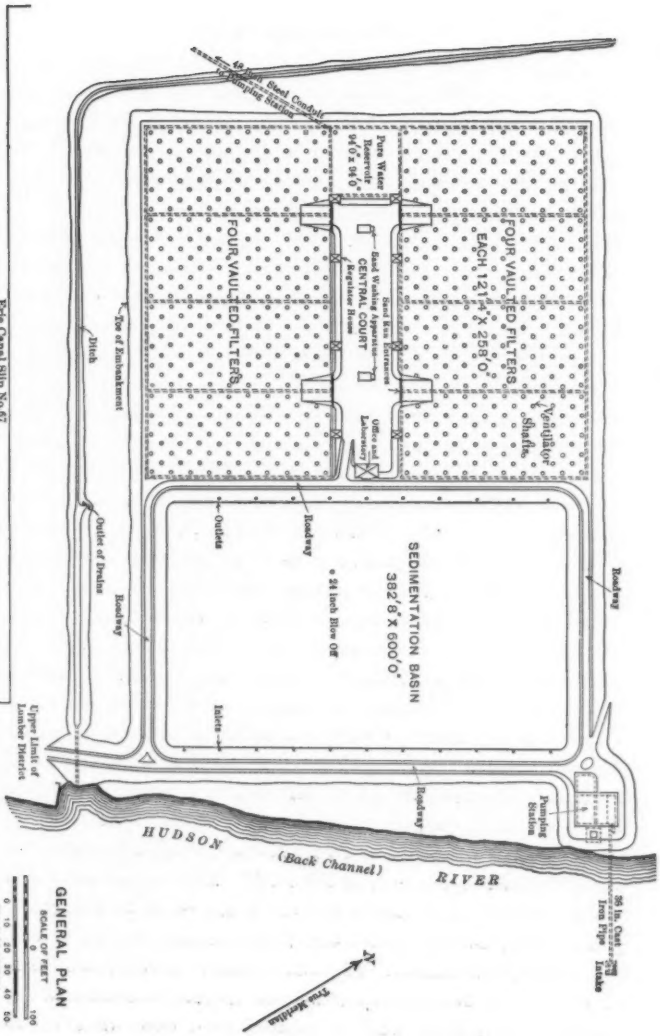

Steel Conduit
Pure Water Reservoir
140 x 140
Sand Washing Apparatus
CENTRAL COURT
Regulator Room
Sand Bins Entrance
Office and Laboratory
FOUR VAULTED FILTERS
EACH 121'4" X 258'0"
Ventilator Shafts
FOUR VAULTED FILTERS
Roadway
SEDIMENTATION BASIN
382'6" X 600'0"
24 Inch Blow Off
Outlets
Inlets
Roadway
Toe of Embankment
Ditch
Outlet of Drains
Roadway
Erie Canal Ship No.67
Upper Limit of Lumber District
Roadway
Pumping Station
36 In. Cast Iron Pipe
Intake
HUDSON
(Back Channel)
RIVER
N
True Meridian
GENERAL PLAN
SCALE OF FEET
0 100 200 300 400 600
SCALE OF METERS

FIG. 4.

two channels remain as during the time covered by the foregoing examinations.

Description of Plant.

The filter plant, and the most important structures connected therewith, are shown in Figs. 3 to 15, and this description, for the most part, will be limited to those points which are not thus shown.

Intake.—The intake is shown by Fig. 6, and consists of a simple concrete structure in the form of a box, having an open top covered with rails 6 ins. apart, and connected below, through a 36-in. pipe, with a well in the pumping station. Before going to the pumps the water passes through a screen with bars 2 ins. apart, so arranged as to be raked readily. The rails over the intake and this screen are intended to stop matters which might obstruct the passageways of the pumps, but no attempt is made to stop fish, leaves or other floating matters which may be in the water. The arrangement, in this respect, is like that of the filter at Lawrence, Mass., where the raw water is not subjected to close screening. There is room, however, to place finer screens in the pump well, should they be found desirable.

Pumps.—The centrifugal pumps were built for the Prindle Pump Company at the Lawrence Machine Shop. They have a guaranteed capacity of 16 000 000 galls. per 24 hours against a lift of 18 ft., or 12 000 000 galls. per 24 hours against a lift of 24 ft., corresponding to a water-horse-power, in either case, of 50.5. The ordinary pumping at low water is against the higher lift, and under these conditions either pump can supply the ordinary consumption, the other pump being held in reserve. The plant is arranged, however, so that if for any reason a large quantity of water is required when only one pump can be used, water can be pumped direct to the filters against the lower head, in which case one pump will deliver a larger quantity, up to 16 000 000 galls., the full nominal capacity of the plant.

The boilers were built by James Hunter, of Albany, and are of the vertical tubular type, each of 100 H.-P. The engines are connected directly to the pumps, and were built by the Watertown Engine Company. The plant is supplied with Dean condensers, feed-water filter, and other appurtenances. The whole plant is in duplicate, either half of which is capable of supplying the ordinary consumption, or the consumption up to the limit of capacity of the filters under the above-mentioned conditions.

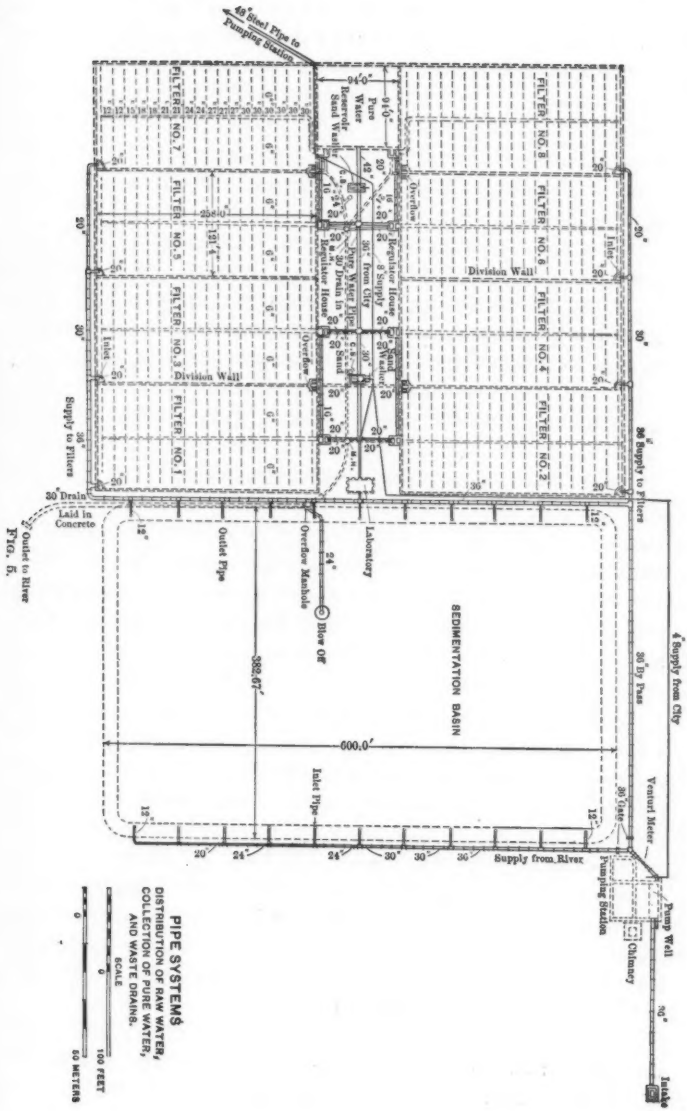

48" Steel Pipe to Pumping Station
Pure Water Reservoir
Sand Washing
Overflow
Regulator House
Supply from City
Division Wall
Inlet
FILTER NO. 8
FILTER NO. 7
FILTER NO. 6
FILTER NO. 5
FILTER NO. 4
FILTER NO. 3
FILTER NO. 2
FILTER NO. 1
Supply to Filters
Drain Laid in Concrete
Outlet to River
Outlet Pipe
Overflow Manhole
Laboratory
Blow Off
SEDIMENTATION BASIN
388.67'
600.0'
Inlet Pipe
Supply from River
Pumping Station
Chimney
Pump Well
Intake
Supply from City
By Pass
Venturi Meter
PIPE SYSTEMS.
DISTRIBUTION OF RAW WATER,
COLLECTION OF PURE WATER,
AND WASTE DRAINS.
SCALE
100 FEET
50 METERS

FIG. 5.

The pumping station building, to a point above the highest flood-level, is of massive concrete construction, without openings. Nearly all the machinery is necessarily below this level, and in high water the sluice gates are closed, and the machinery is thus protected from flooding. The superstructure is of pressed brick, with granite trimmings. The general form of the pumping station and the arrangement of the pumping machinery are shown in Fig. 7. A distant view of the building is shown in Fig. 1, Plate XXXIV.

Meter for Raw Water.—Upon leaving the pumping station the water passes through a 36-in. Venturi meter having a throat diameter of 17 ins., the throat area being two-ninths of the area of the pipe. The meter records the quantity of water pumped, and is also arranged to show on gauges in the pumping station the rate of pumping.

Aeration.—After leaving the meter, the water passes to the sedimentation basin through eleven outlets. These outlets consist of 12-in. pipes on end, the tops of which are 4 ft. above the nominal flow line of the sedimentation basin. Each of these outlet pipes is pierced with 296 $\frac{3}{8}$-in. holes extending from 0.5 to 3.5 ft. below the top of the pipe. These holes are computed so that when 11 000 000 galls. of water per day are pumped, all the water will pass through the holes, the water in the pipes standing flush with the tops. The water is thus thrown out in 3 256 small streams, and becomes aerated. When more than the above amount is pumped, the excess flows over the tops of the outlet pipes in thin sheets, which are broken by the jets.

Regarding the necessity for aeration, no observations have been taken upon the Hudson River, but, judging from experience with the Merrimac, at Lawrence, where the conditions are in many respects similar, the water is at all times more or less aerated, and, for the greater part of the year, it is nearly saturated with oxygen, and aeration is not necessary. During low water in summer, however, there is much less oxygen in the water, and at these times aeration is a distinct advantage. Further, the river water will often have a slight odor, and aeration will tend to remove it. The outlets are arranged so that they can be removed readily in winter, if they are not found necessary at that season.

Sedimentation Basin.—The sedimentation basin has an area of 5 acres and is 9 ft. deep. To the overflow, it has a capacity of 14 600 000 galls., and, to the flow line of the filters, 8 900 000 galls. There is thus

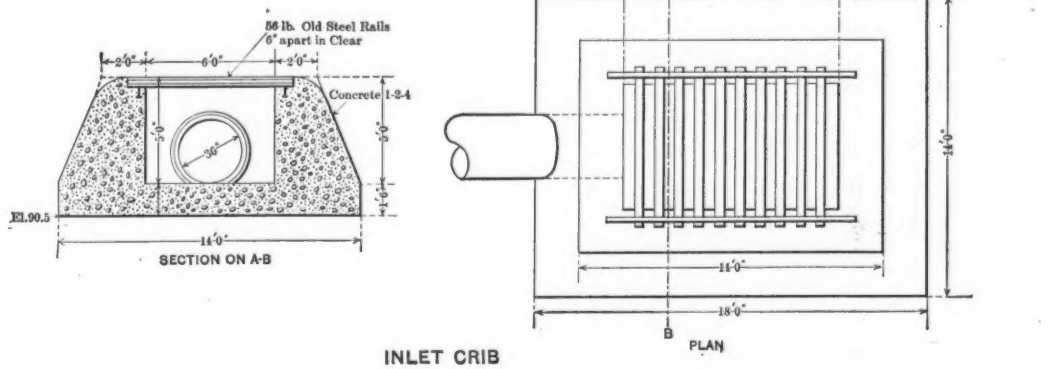

56 lb. Old Steel Rails
6" apart in Clear
2'0"
6'0"
2'0"
Concrete 1-2-4
5'0"
30"
1'6"
EL.90.5
14'0"
SECTION ON A-B
A
10'0"
14'0"
14'0"
18'0"
B
PLAN
INLET CRIB
125
120
110
100
90
80
H U D S O N R I V E R
Pumping Station
Concrete 1-2-4
Rough Stone Paving
Extreme Low Water EL98.6
Mean High Water EL102.3
Gate
EL92.0
36 Inch Cast Iron Pipe, Length 197 Feet
EL93.0
EL97.0
Inlet Crib
6+72
8+75
8+50
8+25
8+00
7+75
7+50
7+25
7+00
6+75
6+50
PROFILE OF INTAKE PIPE

FIG. 6.

a reserve capacity of 5 700 000 galls. between these limits, and this amount can be drawn upon, without inconvenience, for maintaining the filters in service while the pumps are shut down. This allows a freedom in the operation of the pumps, which would not exist with the water supplied direct to the filters.

The sedimentation basin is built on the river bank, largely above the natural surface of the soil. The sides are embankments made of clay obtained in excavating for the filters, mixed with gravel dredged from the river. These materials were put down in alternate 3-in. layers, wet, and harrowed, and were rolled with 3-ton grooved rollers on the top of each gravel layer until the gravel was forced down into and thoroughly embedded in the clay. The embankments made in this way are extremely solid, stand up in vertical sections when cut, are not readily washed, and no leakage through them has appeared at any point. The outsides of the embankments are covered with soil, and the inside and bottom with 16 ins. of puddle, which is protected from frost on the sides by covering with gravel, above which is a rough blue-stone pavement.

The puddle was made by mixing equal volumes of the clay obtained in excavating for the filters, and mixed sand and gravel obtained from the river by dredging. It differed from the material of the embankments only in more thorough mixing, and greater care in placing. The materials were mixed in a pug mill. It was soon found that the best mixing was secured with rather large quantities of water, while the best ramming required that the materials should not be too wet. Accordingly, the materials were mixed wet, given a preliminary ramming, allowed to stand two or three days, or as long as was necessary, depending upon the weather, and afterward given the final ramming. If the whole became too dry, in the interval, it was moistened at this time. The puddle was put down in three layers, and the concrete rested directly upon it. The concrete was put down in blocks about 7 ft. square, with $\frac{1}{2}$-in. joints, extending half-way from top to bottom, filled with asphalt. The maximum rate of placing puddle was about 3 000 cu. yds. per month.

The water enters the sedimentation basin from eleven inlets along one side and is withdrawn from eleven outlets directly opposite. The inlets and aerating devices described previously bring the water into the basin without current, and evenly distributed along one side.

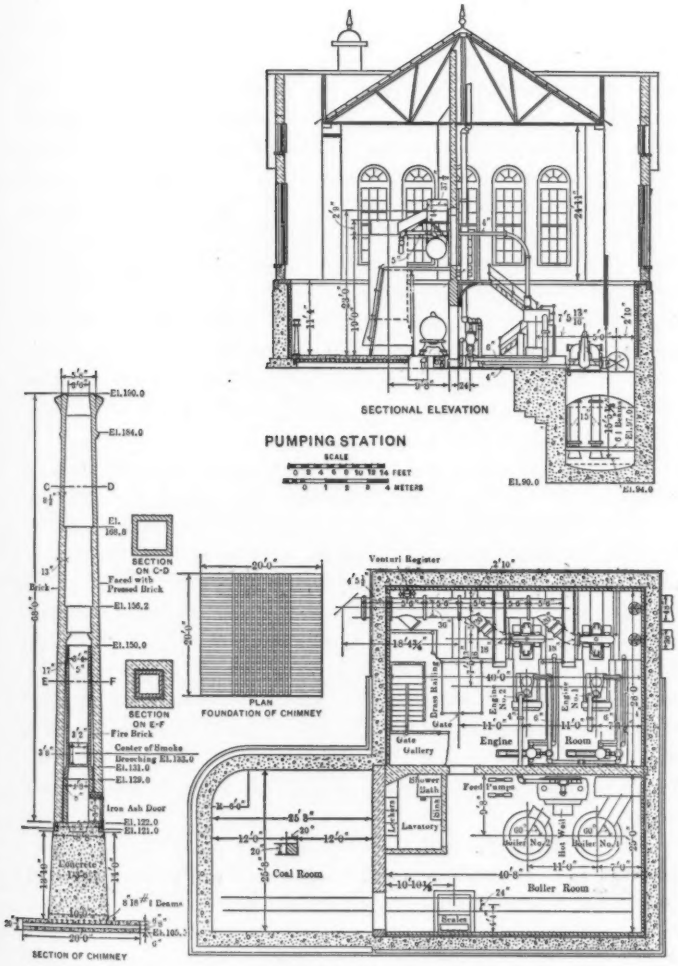

SECTIONAL ELEVATION
PUMPING STATION
SCALE
0 2 4 6 8 10 12 14 FEET
0 1 2 3 4 METERS
El. 90.0
El. 94.0
El. 190.0
El. 184.0
El. 168.8
SECTION ON C-D
Faced with Pressed Brick
El. 156.2
El. 150.0
SECTION ON E-F
Fire Brick
Center of Smoke Breeching El. 133.0
El. 131.0
El. 129.0
Iron Ash Door
El. 122.0
El. 121.0
Concrete
8 18" I Beams
El. 105.
SECTION OF CHIMNEY
PLAN FOUNDATION OF CHIMNEY
Venturi Register
Engine Room
Boiler Room
Coal Room
Lavatory
Lockers
Shower Bath
Feed Pumps
Scales
Gate Gallery
Boiler No. 1
Boiler No. 2
Boiler No. 3
Boiler No. 4
Brick Wall
Engine No. 1
Engine No. 2
Engine No. 3
Engine No. 4
Gate

FIG. 7.

Both inlets and outlets are controlled by gates, so that any irregularities in distribution can be avoided. The floor of the sedimentation basin is built with even slopes from the toe of each embankment to a sump, the heights of these slopes being 1 ft., whatever their lengths. The sump is connected with a 24-in. pipe leading to a large manhole in which there is a gate through which water can be drawn to empty the basin. There is an overflow from the basin to this manhole, which makes it impossible to fill the basin above the intended level. A section of the embankment about the sedimentation basin and other details are shown in Fig. 8. The method of placing the concrete floors is shown in Fig. 2, Plate XXXII, while a view of a portion of the finished basin in use is shown in Fig. 1, Plate XXXIV.

When the basin is being cleaned, the supply is maintained by opening the by-pass from the pumps to the filters and pumping to them direct. Cleaning can be done during periods of continued clear weather, such as occur in the summer and fall, without the slightest detriment to the filters, and it will not be necessary to clean it oftener than once a year.

No special provision is made for flushing out the mud; but, by opening the gates on the inlet and outlet pipes, water can be introduced at twenty-two points along two sides of the basin, and it is believed that this, with the slope of the bottom, will be sufficient to enable the mud to be swept out readily.

Filters.—The filters are of masonry, and are covered to protect them against the winters, which are quite severe in Albany. The piers, cross-walls and linings of the outside walls, entrances, etc., are of vitrified brick. All other masonry is concrete. The average depth of excavation for the filters was 4 ft., and the material at the bottom was usually blue or yellow clay. In some places shale was encountered. In one place soft clay was found, and there the foundations were made deeper.

Floors.—The floors consisted of inverted, groined, concrete arches, arranged to distribute the weight of the walls and vaulting over the whole area of the bottom. The bottoms were put in in alternate squares running diagonally with the pier lines, as shown in Fig. 1, Plate XXX. In this way forms could be used giving the shape of the arches, and the surface of the concrete was brought to the required form by screeds. After the concrete had set, the forms were removed

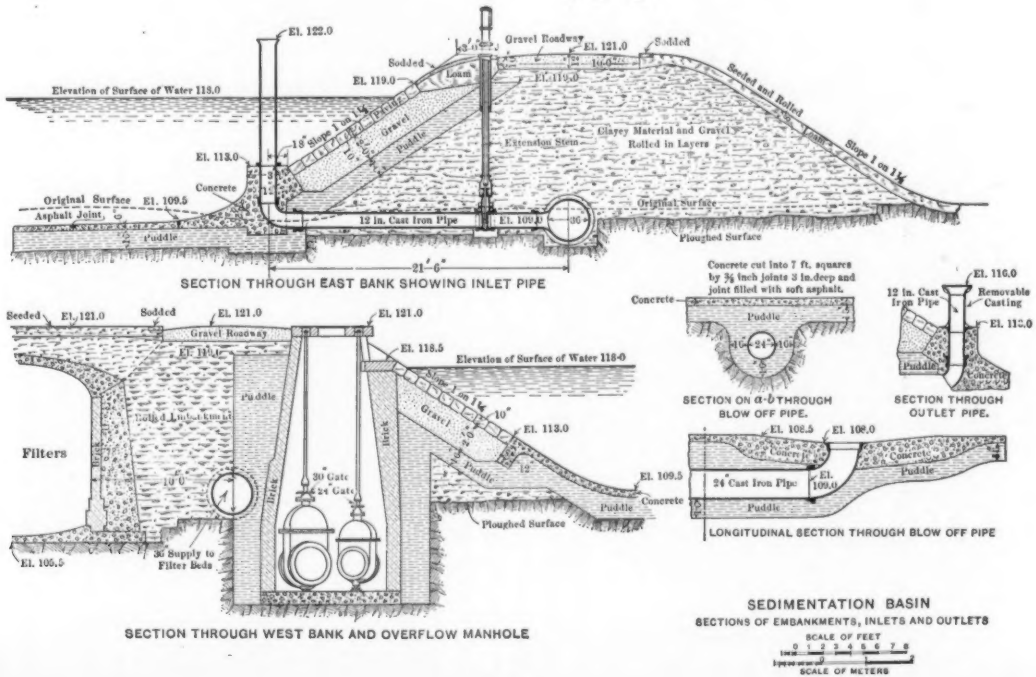

El. 122.0
Gravel Roadway
El. 121.0
Sodded
Sodded
El. 119.0
Loam
Elevation of Surface of Water 118.0
Seeded and Rolled
Slope 1 on 1¼
18" Slope 1 in 1¼
Gravel
Puddle
Extension Stem
Clayey Material and Gravel Rolled in Layers
El. 113.0
Concrete
Original Surface
El. 109.5
Asphalt Joint
12 in. Cast Iron Pipe
El. 109.0
Original Surface
Ploughed Surface
21'-0"
SECTION THROUGH EAST BANK SHOWING INLET PIPE
Seeded
El. 121.0
Sodded
El. 121.0
Gravel Roadway
El. 121.0
El. 118.5
Elevation of Surface of Water 118.0
Filters
Solid Embankment
Puddle
Brick
Slope 1 on 1¼
Gravel
10"
El. 113.0
30" Gate
24" Gate
Ploughed Surface
El. 109.5
Concrete
Puddle
El. 105.5
36" Supply to Filter Beds
SECTION THROUGH WEST BANK AND OVERFLOW MANHOLE
Concrete cut into 7 ft. squares by ¾ inch joints 3 in. deep and joint filled with soft asphalt.
Concrete
Puddle
SECTION ON a-b THROUGH BLOW OFF PIPE.
El. 116.0
12 in. Cast Iron Pipe
Removable Casting
El. 112.0
Puddle
Concrete
SECTION THROUGH OUTLET PIPE.
El. 108.5
El. 108.0
Concrete
Concrete
24" Cast Iron Pipe
El. 109.0
Puddle
Puddle
LONGITUDINAL SECTION THROUGH BLOW OFF PIPE
SEDIMENTATION BASIN
SECTIONS OF EMBANKMENTS, INLETS AND OUTLETS
SCALE OF FEET
0 1 2 3 4 5 6 7 8
SCALE OF METERS

FIG. 8.

and the concrete for the intermediate blocks was placed, using screeds to bring the surfaces to the lines given by the blocks already in position. The foundations for the outside walls were put in in alternate sections, the lengths of the sections being usually about 10 ft.

Walls.—For the outside walls the brick linings, 8 ins. thick, were built first to the full height. A certain number of bricks were laid endways, and projected into the concrete. The projecting bricks occupied about 4% of the area of the wall. Afterward, wooden forms were put up on the outside, and the concrete backing was filled in. Sections of the walls are shown in Fig. 10. The arrangement of the projecting brick is shown in Fig. 1, Plate XXXII, which also shows the outside forms for the concrete wall in the distance.

In stopping the day's work on the outside walls, the concrete was stepped off, the horizontal joints being made at least four times as long as the vertical joints. This bonding proved adequate, and no cracks have followed the joints made in this way. The horizontal joints were strengthened further by driving a wooden stick into the concrete before stopping the work. This was removed afterward, and, when more concrete was added, it formed a thick tongue in the old work. By using sticks, in which deep grooves were cut, and with a slight batter, they could be taken out without trouble and used again indefinitely.

The outside walls are thus practically monolithic, and differ in this respect from the floors and vaulting, which are made in sections, the dimensions of which do not exceed 14 ft.

Vaulting.—The concrete vaulting was placed on wooden centers supported on wedges which could be knocked out after the concrete had set, so that the centers came down readily, and could be moved forward and used again. Some of the centers were used four or five times in the course of the work, the only repairs necessary being the patching of the lagging, and they were in good order at the end of the work. The vaulting was designed with a clear span of 12 ft., a rise of $2\frac{1}{2}$ ft., and a thickness of 6 ins. at the crown, but the clear span was reduced to 11 ft. 11 ins. to fit the sizes of the bricks in the piers. It was put in in squares, the joints being on the crowns of the arches parallel with the lines of the piers, and each pier being the center of one square. The manholes are in alternate sections, and are of concrete, built in steel forms with castings at the tops, securely jointed to the concrete.

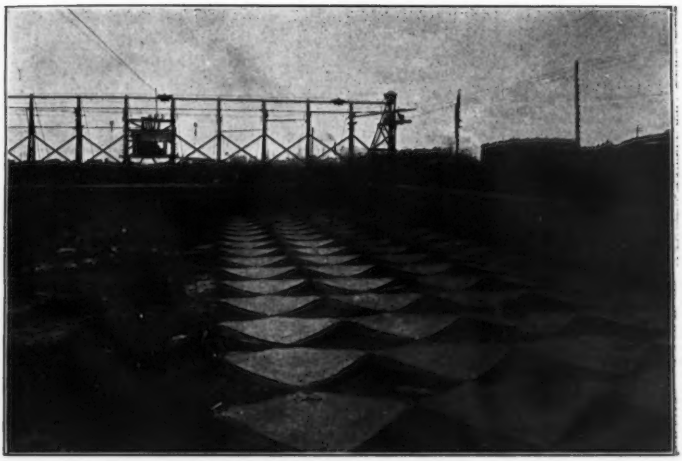


FIG. 1.—PLACING THE FLOOR OF A FILTER.

FIG. 2.—BUILDING THE BRICK PIERS.

As the centers for the vaulting were moved forward, it was necessary that they should fit closely the piers and walls in their new positions. The lumber for the centers was cut by machinery, and was of uniform dimensions. Considerable care was required to make sure that the distances between the piers, and between the piers and the walls, should always be exactly right to fit the woodwork. This was accomplished by stopping the work two courses before the top, and giving new lines and grades at this elevation, after which the two upper courses were placed. An opportunity was thus given to correct any slight variations which might have crept in below this level. This procedure was much facilitated on the walls by projecting the upper courses of brick about $\frac{1}{2}$ in., making a slight cornice. Variations of $\frac{1}{2}$ in. or so below this level do not show. Such projections were not used on the piers in this case, but their use would have added to the convenience of construction and the appearance of the finished work.

Above the vaulting there are 2 ft. of earth and soil, grassed on top. The tops of the manholes are 6 ins. above the soil to prevent rain water from entering them. The drainage of the soil is effected by a depression of the vaulting over each pier, partially filled with gravel and sand, from which water is removed by a 2-in. tile drain going down the center of the pier and discharging through its side just above the top of the sand in the filter. The saving in cost by this arrangement was considerable, as the cost of the drains was much less than that of the concrete which would have been necessary to fill the areas over the piers had any other system been adopted. Further, the water entering in this way is as good as any water available, and there is every reason for adding it to the supply. It enters the supply before it passes through the filters. Sections of the vaulting are shown in Fig. 10; details of the centering used are shown in Fig. 13. In Plate XXXI, Fig. 1 shows the placing of concrete, and Fig. 2 gives a general view of the vaulting at various stages. The finished vaulting is shown from beneath in Plate XXXIII, Figs. 1 and 2.

In order to provide ready access to each filter, a part of the vaulting near one side is elevated and made cylindrical in shape, making an inclined runway from the sand level to a door, the threshold of which is 6 ins. above the level of the overflow. This sand-run is provided with permanent timber runways and with secure doors.

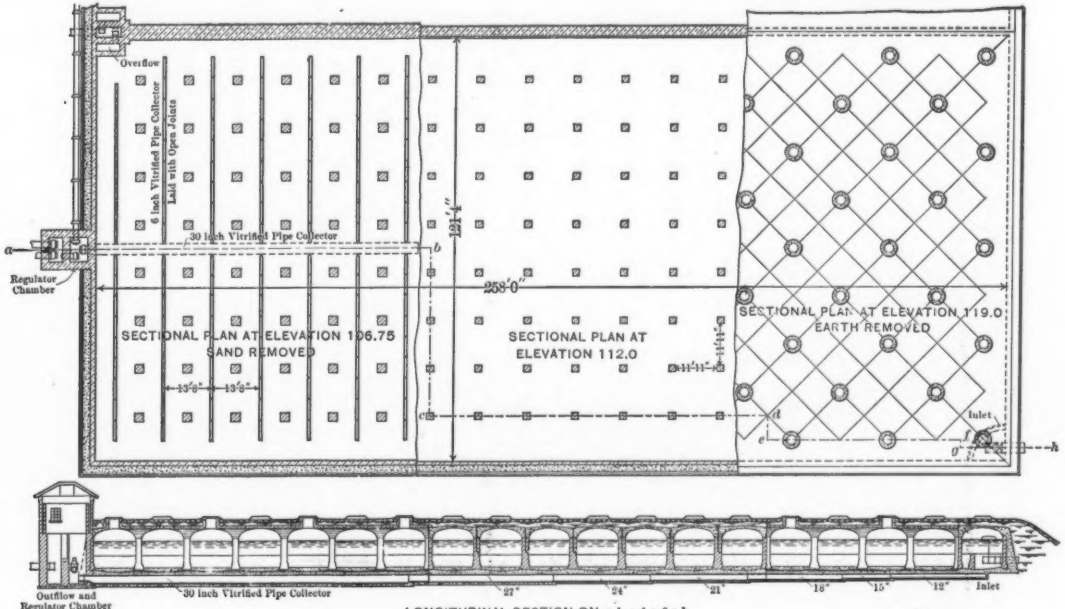
The manholes of the filters are provided with double covers of steel

plates to exclude the cold. The covers also exclude light. When cleaning the filters, light can be admitted by removing the covers. Supports for electric lights are placed in the vaulting, so that the filters can be lighted by electricity and the work of cleaning can be done at night, and in winter under heavy snow, without removing the covers. The electric lights have not yet been installed. The supports for this purpose are castings, which were put at regular places on the centers and surrounded by concrete in the vaulting. They are strong enough, and are placed so as to serve for an overhead carrier system for removing the sand, should that be found advantageous in the future. For the present, the plan is to run out the sand in wheel-barrows, as is commonly done in European filter plants, and thus far in this country. The possibility of putting overhead rails with suspended buckets for carrying out the dirty sand seemed quite promising, but prices secured on the installation of machinery were so great as not to justify it for the removal of the quantity of sand estimated as necessary to be taken out from the filters.

The regulator houses, the entrances to the sand-runs, and all exposed work are of pressed brick, with Milford granite trimmings and slate roofs. The regulator houses have double walls and double windows, and a tight ceiling in the roof, to make them as warm as possible and to avoid the necessity of artificial heat to prevent freezing.

The vaulting is similar, in many respects, to that of the covered filters at Ashland, Wis., and at Somersworth, N. H., but differs from that vaulting, in that it is entirely of concrete instead of brick backed by concrete.

Underdrains.—The main underdrains for removing the filtered water are of vitrified pipe surrounded by concrete, and are entirely below the floors of the filters. These drains were put in before the construction of the filters was commenced, and the concrete surrounding them was brought to the plane of the bottom of the foundations, so that when the floor was built it went over them continuously, without breaking in any way the line of inverted arches. This arrangement was adopted because the drains would have been in the way if they had been placed entirely above the floor, and if any part of the drain had been placed in the normal floor-span it would have reduced the strength of the inverted arches, and might itself have been broken by their pressure. As the surrounding material is clay or tight



FILTER BEDS

PLAN AND SECTION OF FILTER NO. 2

FIG. 9.

rock, no danger of loss of water by seepage can result from this arrangement.

The main effluent collectors are 30-in. vitrified pipes, reduced by castings to 20 ins. at the outlets, and the effluent from each filter passes through a 20-in. gate. The underdrains are made much larger than would ordinarily be required for carrying the quantities of water involved. The reason for this is that, after a filter has just been scraped, the friction of the water in passing the sand is very slight. If the friction of the underdrainage system is not kept very low, there will be so much loss of head that when a filter is started the pull exerted at remote parts of the filter will be less than at points near the outlet, and thus the parts near the outlet will operate at rates which are too high, while the more remote parts will hardly filter at all, and the resulting purification is less than it should be. The underdrainage system is so designed that, when starting a filter after cleaning, the friction of the sand is about 50 mm. at a rate of 3 000 000 galls. per acre daily, and the friction of the underdrainage system is estimated at 10 mm. This very low friction, which is necessary, is obtained by the use of ample sizes for the underdrains and low velocities in them. In the outlet and measuring devices moderate losses of head are not objectionable, and the sizes of the pipes and connections are, therefore, smaller than the main underdrains.

Connections with the drain are made through thirty-eight 6-in. outlets in each filter, passing through the floor and connected with 6-in. lateral drains running through the whole width of the filter. These drains were made with pipes having one side of the bell cut off, so that they would lie flat on the floor and make concentric joints, without support and without having to be wedged. They were laid with a space of about 1 in. between the barrels, leaving a large opening for the admission of water from the gravel. The general arrangement of the drainage system is shown in Fig. 5. Other details are shown in Figs. 9 and 10, while the computed frictional resistance of one filter is shown in Fig. 11.

Filter Gravel.—The gravel surrounding the underdrains is of three grades. The material was obtained from the river-bed by dredging, and was of the same stock as that used for preparing ballast for the concrete. It was separated and cleaned by a special, cylindrical, revolving screen. The coarsest grade of gravel was that which would not

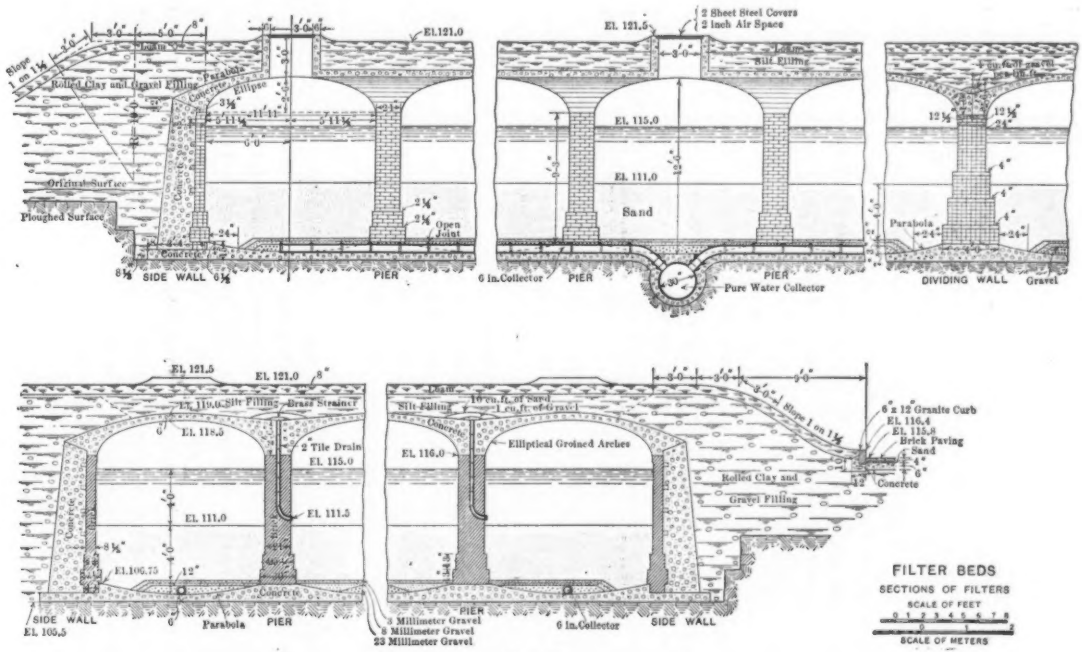

El. 121.0
Rolled Clay and Gravel Filling
Parabola
Ellipse
Original Surface
Ploughed Surface
Concrete
Open Joint
SIDE WALL
PIER
El. 121.5
2 Sheet Steel Covers
2 Inch Air Space
Silt Filling
El. 115.0
El. 111.0
Sand
6 in. Collector
Pure Water Collector
DIVIDING WALL
Gravel
El. 111.5
2 Tile Drain
El. 118.5
Brass Strainer
Elliptical Groined Arches
Rolled Clay and Gravel Filling
6" x 12" Granite Curb
El. 116.4
El. 115.8
Brick Paving
Sand
Concrete
SIDE WALL
El. 105.5
Parabola
3 Millimeter Gravel
8 Millimeter Gravel
23 Millimeter Gravel
FILTER BEDS
SECTIONS OF FILTERS
SCALE OF FEET
SCALE OF METERS

FIG. 10.

pass round holes 1 in. in diameter, and free from stones more than about 2 ins. in diameter. At first it was required to pass a screen with holes 2 ins. in diameter, but this screen removed many stones which it was desired to retain, and the screen was afterward changed to have holes 3 ins. in diameter. The intermediate grades of gravel passed the 1-in. holes, and were retained by a screen with round holes $\frac{3}{8}$ in. in diameter. The finest gravel passed the above screens and was retained by a screen with round holes $\frac{3}{16}$ in. in diameter. The gravel was washed, until free from sand and dirt, by water played upon it during the process of screening, and it was afterward taken over screens in the chutes where it was separated from the dirty water, and, when necessary, further quantities of water were played upon it at these points.

The average mechanical analyses of the three grades of gravel are shown by Fig. 14. Their effective sizes were 23, 8 and 3 mm., respectively, and, for convenience, they are designated by these numbers. The average uniformity coefficent for each grade was about 1.8.

The 23-mm. gravel entirely surrounded the 6-in. pipe drains, and was carried slightly above their tops. In some cases it was used to cover nearly the whole of the floor, but this was not insisted upon.

The 8-mm. gravel was obtained in larger quantity than the other sizes, and was used to fill all spaces up to a plane $2\frac{1}{2}$ ins. below the finished surface of the gravel, this layer being about 2 ins. thick over the tops of the drains, and somewhat thicker elsewhere.

The 3-mm. gravel was then applied in a layer $2\frac{1}{2}$ ins. deep, and the surface leveled. The grades for the two upper gravel layers were shown directly by the joints in the brick work of the piers.

The form of construction made it best to put a lateral drain in each section, or 13 ft. 8 ins. apart on centers. The drain itself occupies 7 ins., and the longest course which water has to pass in the gravel, in any event, is about $6\frac{1}{2}$ ft. This distance is so short that the frictional resistance of the filtered water in passing through the gravel is extremely small, and, therefore, it was possible to vary the gravel sections somewhat according to the relative amounts of gravel of the several grades obtained in screening, without detriment to the work. The thickness of the 3-mm. gravel was varied between 2 and $2\frac{1}{2}$ ins., according to the supply available, and similar variations were made in the other grades; but the finished surface of the gravel was always kept

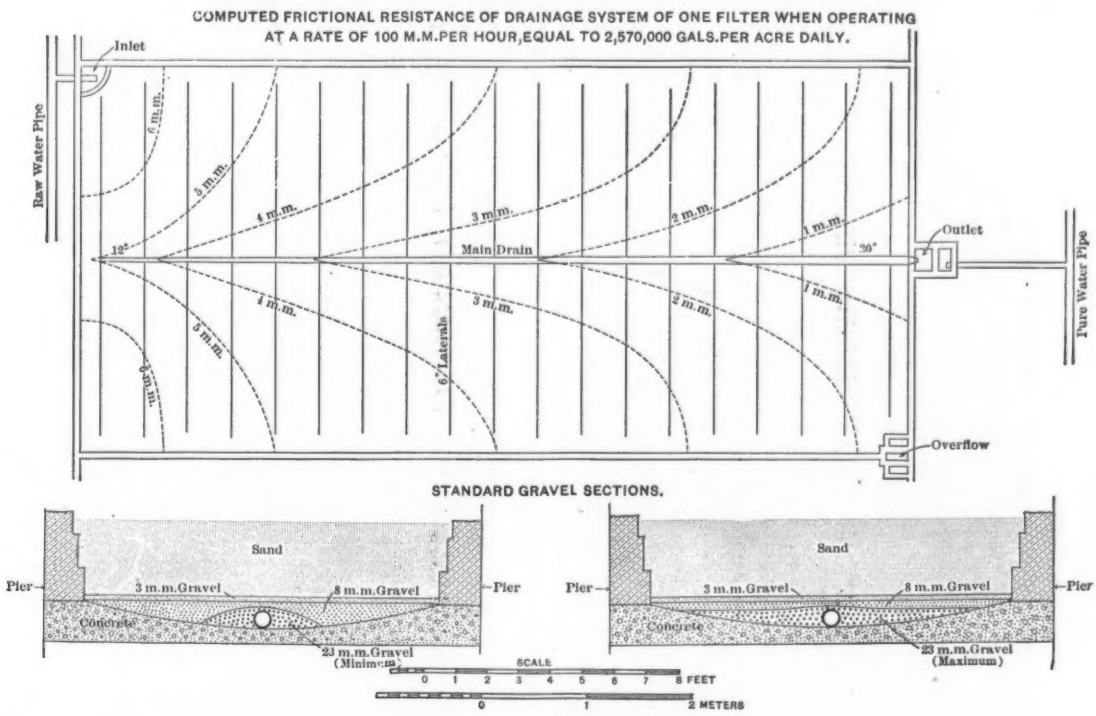

COMPUTED FRICTIONAL RESISTANCE OF DRAINAGE SYSTEM OF ONE FILTER WHEN OPERATING AT A RATE OF 100 M.M.PER HOUR, EQUAL TO 2,570,000 GALS.PER ACRE DAILY.
Inlet
Raw Water Pipe
6 m.m.
5 m.m.
4 m.m.
3 m.m.
2 m.m.
1 m.m.
12°
Main Drain
30°
Outlet
Pure Water Pipe
Overflow
6" Laterals
STANDARD GRAVEL SECTIONS.
Sand
Pier
3 m.m.Gravel
8 m.m.Gravel
Concrete
23 m.m.Gravel (Minimum)
23 m.m.Gravel (Maximum)
SCALE
0 1 2 3 4 5 6 7 8 FEET
0 1 2 METERS

FIG. 11.

at the same elevation. Typical sections of the arrangements of the gravels are shown in Figs. 10 and 11, and in Fig. 1, Plate XXXIII. The greatest rate at which gravel was obtained and placed was about 1 500 cu. yds. per month.

Filter Sand.—The preliminary estimates of cost were based upon the use of filter sand from a bank near the filter site. Further examination showed that this sand contained a considerable quantity of lime, and it was found by experiment with a small filter constructed for that purpose that the use of this sand would harden the water by about 2 parts in 100 000, and the amount of lime contained in the sand, namely, about 7%, was sufficient to continue this hardening action for a considerable number of years. This was regarded as a serious objection to its use, and the specifications were drawn limiting the amount of lime in the sand. This excluded all of the local bank sands. The river sands which were used were nearly free from lime, and, in the end, the sand as secured was probably not only free from lime, but more satisfactory in other ways, and also cheaper than the bank sand would have been.

The sand was obtained from the river at various places by dredging. It was first taken up by dipper-dredges, and brought in scows to a point in the back channel a little north of the filter plant. It was there dumped in a specially prepared place in the bottom of the river, from which it was lifted by a hydraulic dredge and pumped through a 15-in. pipe an average distance of 525 ft. to points selected, and varied from time to time, on the flats north of the filters. The water containing the sand was then put through screens having meshes which excluded all stones 5 mm. in diameter and over, and was then taken into basins where the sand was deposited in conical-shaped piles, the water running over the surface and away. The boards around the edges were always kept so low as to prevent ponding and the consequent deposition of fine particles of dirt with the sand. After a certain amount of sand was deposited in one place, the point of discharge was changed, the pile drained, inspected, and, if found satisfactory, carried to the filters.

As the work progressed, an improvement upon this method was made. Piles were driven throughout the area in which the sand was deposited, a bridge was constructed, and the sand trucks passed over it. Sand was shoveled continuously into the trucks, new sand

FIG. 1.—PLACING THE CONCRETE VAULTING.

FIG. 2.—GENERAL VIEW OF VAULTING, UNDER CONSTRUCTION.

taking the place of that shoveled out. Afterward, a steam dredge was installed, which took the place of a part of the shovelers. With this arrangement the sand was delivered constantly in one place, and the necessity for changing the position of the screen was avoided.

A considerable amount of the finer part of the sand was removed by this process and accumulated below. This material was not suitable for filter sand and was wasted. Some of it was afterward used for filling. The gravel removed from the sand was used under the pavement of the sedimentation basin, and a part of it was screened for filter gravel. The capacity of the dredge was about 500 cu. yds. per day, scow measurement; but owing to the losses and wastes, and the greater compactness of the sand in the filters, the amount of sand secured, as shown by the final measurements, did not exceed 7 500 cu. yds. per month.

The specifications of the filter sand require that:

"The filter sand shall be clean river, beach or bank sand, with either sharp or rounded grains. It shall be entirely free from clay, dust or organic impurities, and shall, if necessary, be washed to remove such materials from it. The grains shall, all of them, be of hard material, which will not disintegrate, and shall be of the following diameters: Not more than 1% by weight, less than 0.13 mm, nor more than 10% less than 0.27 mm.; at least 10% by weight shall be less than 0.36 mm. and at least 70%, by weight, shall be less than 1 mm., and no particles shall be more than 5 mm. in diameter. The diameters of the sand grains will be computed as the diameters of spheres of equal volume. The sand shall not contain more than 2%, by weight, of lime and magnesia taken together and calculated as carbonates."

With the river sand and the method of handling adopted by the contractors, it was possible to control the quality of the sand, so that the specifications were complied with. In the lower layers of two of the filters a little sand was allowed which contained a few particles above 5 mm. in diameter. The screens were adjusted afterward so that the largest remaining particles were less than 4 mm. in diameter. The filter sand has effective sizes of from 0.29 to 0.32 mm., averaging 0.31; and uniformity coefficients from 2.2 to 2.5, averaging 2.3. The voids in the sand when closely packed amount to about 40% of the total volume. Its mechanical composition is shown by the diagram, Fig. 14.

The sand and also the gravel were delivered in the filters through the manholes, temporary plank roadways being built for that purpose. Trucks carrying 1½ yds., with a pair of horses, were driven over the

vaulting in all directions, without hesitation and without damage to it. The sand was dumped on plank platforms constructed below. A record was kept of all the planks used for this purpose, and they were required to be taken up in the presence of inspectors afterward to prevent the possibility of leaving any of them in the filter. This arrangement necessitated working over all the sand underneath the points of dumping, and it thereby became loosened from the excessive packing caused by dumping it from a height. The sand was deposited in three horizontal layers, so that, if by accident sand of unusual quality was placed at any point, the same kind of sand would not extend from top to bottom. The method of placing the sand in layers is shown in Fig. 1, Plate XXXIII, which also shows the gravel layers and a lateral underdrain; while a completed filter with the sand smoothed ready for use is shown in Fig, 2, Plate XXXIII.

Sand-Washing Apparatus.—Most of the suspended matters in the filtered water are held by the top layer of sand, and this layer is removed from time to time. The dirty sand is washed, and eventually replaced in the filters. Two ejector sand-washing machines, shown in Fig. 15, are provided at convenient places between the filters. In them the dirty sand is mixed with water, and is thrown up by an ejector, after which it runs through a chute into a receptacle, from which it is again lifted by another ejector. It passes in all through five ejectors, part of the dirty water being wasted each time. The sand is finally collected from the last ejector, where it is allowed to deposit from the water.

Sand washers of this kind have been used for many years by some of the London water companies, and more recently at Hamburg; and also at Lawrence and Poughkeepsie in this country. The entire central court between the filters and about the sand washers, shown in Fig. 2, Plate XXXIV, is paved with brick upon a concrete foundation, and affords a convenient space for handling and storing sand.

Inlets to Filters.—Water is admitted to each filter through a 20-in. pipe from a pipe system connecting with the sedimentation basin. Just inside of the filter wall is placed a standard gate and beyond that a balanced valve connected with an adjustable float to shut off the water when it reaches the desired height on the filter (Fig. 12). These valves and floats were constructed from special designs, and are similar in principle to valves used for the same purpose in the Berlin water filters.

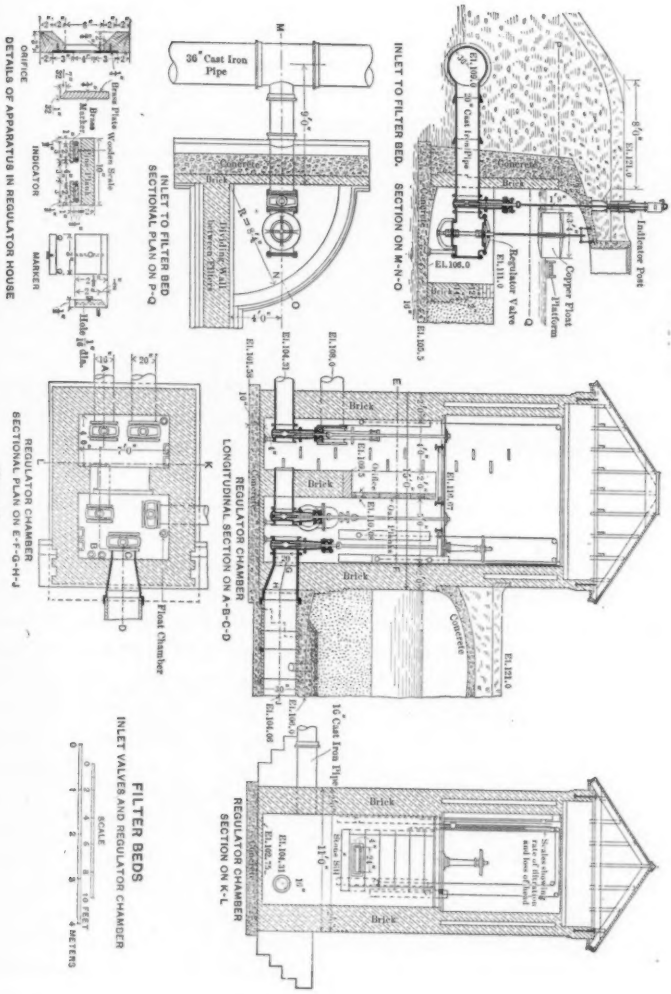

FILTER BEDS
INLET VALVES AND REGULATOR CHAMBER
SCALE
10 FEET
4 METERS
INLET TO FILTER BED. SECTION ON M-N-O
INLET TO FILTER BED SECTIONAL PLAN ON P-Q
REGULATOR CHAMBER LONGITUDINAL SECTION ON A-B-C-D
REGULATOR CHAMBER SECTIONAL PLAN ON E-F-G-H-J
REGULATOR CHAMBER SECTION ON K-L
DETAILS OF APPARATUS IN REGULATOR HOUSE
ORIFICE
INDICATOR
MARKER
Indicator Post
Copper Float
Platform
Regulator Valve
Float Chamber
Brick
Concrete
Screen
Waste-weir at rate of filtration and loss of head

Fig. 12.

Overflows.—Each filter is provided with an overflow, so arranged that it cannot be closed, which prevents the water level from exceeding a fixed limit in case the balanced valve fails to act. An outlet is also provided near the sand run, so that unfiltered water can be removed quickly from the surface of the filter, should it be necessary, to facilitate cleaning.

Filter Outlets.—The outlet of each filter is through a 20-in. gate controlled by a standard graduated to show the exact distance the gate is open. The water rises in a chamber and flows through an orifice in a brass plate 4 by 24 ins., the center of which is 1 ft. below the level of the sand line. At the nominal rate of filtration, 3 000 000 galls. per acre daily, 1 ft. of head is required to force the water through the orifice. With other rates the head increases or decreases approximately as the square of the rate and forms a measure of it. With water standing in the lower chamber, so that the orifice is submerged, it is assumed that the same rates will be obtained with a given difference in level between the water on the two sides of the orifice, as from an equal head above the center of the orifice when discharging into air. The general arrangement of the gate-houses, including the gates for wasting the effluent to the river, for filling filters with filtered water from below, etc., is shown in Fig. 12, while outside views of gate-houses are shown in Fig. 2, Plate XXX, and Fig. 2, Plate XXXIV.

Measurement of Effluent.—In order to show the rate of filtration two floats are connected with the water on the two sides of the orifice. These floats are counterbalanced; one carries a graduated scale and the other a marker which moves in front of the scale and shows the rate of filtration corresponding to the difference in level of the water on the two sides. When the water in the lower chamber falls below the center of the orifice, the water in the float chamber is, nevertheless, maintained at this level. This is accomplished by making the lower part of the tube water-tight, with openings just at the desired level, so that when the water falls below this point in the outer chamber it does not fall in the float chamber.

To prevent the loss of water in the float chamber by evaporation, or from other causes, a lead pipe is brought from the other chamber and supplies a driblet of water to it constantly; this overflows through the openings, and maintains the water level at precisely the desired point. The floats thus indicate the difference in water level on the two sides

FIG 1.—OUTSIDE WALL, READY FOR CONCRETE BACKING.

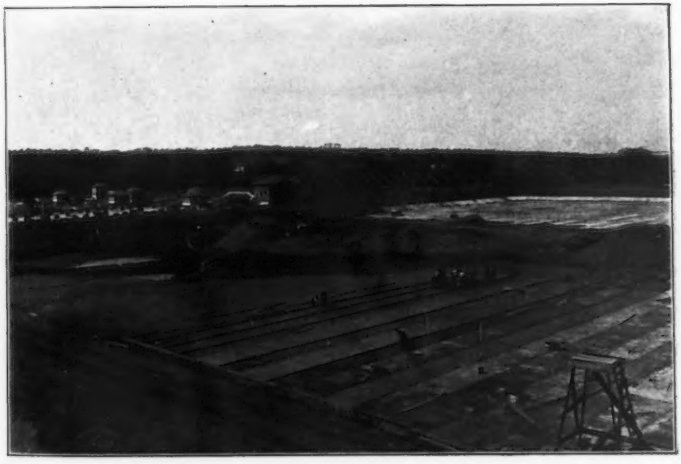


FIG. 2.—SEDIMENTATION BASIN; SHOWING CONSTRUCTION OF FLOOR.

of the orifice whenever the water in the lower chamber is above the center of the orifice; otherwise, they indicate the height of water in the upper chamber above the center of the orifice, regardless of the water level in the lower chamber. The scale is graduated to show the rates of filtration in millions of gallons per acre of filtering area. In computing this scale the area of the filters is taken as 0.7 acre and the coefficient of discharge as 0.61.

At the ordinary rates of filtration the errors introduced by the different conditions under which the orifice operates will rarely amount to as much as 100 000 galls. per acre daily, or one-thirtieth of the ordinary rate of filtration. Usually they are much less than this. The apparatus thus shows directly, and with substantial accuracy, the rate of filtration under all conditions.

Measurement of Loss of Head.—Two other floats with similar connections show the difference in level between the water standing on the filter and the water in the main drain pipe back of the gate, or in other words, the frictional resistance of the filter, including the drains. This is commonly called the loss of head, and increases from 0.2 ft. or less, with a perfectly clean filter, to 4 ft. with the filter ready for cleaning. When the loss of head exceeds 4 ft. the rate of filtration cannot be maintained at 3 000 000 galls. per acre daily with the outlet devices provided, and, in order to maintain the rate, the filter must be cleaned.

Adjustment of Gauges.—The adjustment of the gauges showing the rate of filtration and loss of head is extremely simple. When a filter is put in service the gates from the lower chamber to the pure-water reservoir and to the drain are closed, the outlet of the filter opened, and both chambers allowed to fill to the level of the water on the filter. The length of the wire carrying the gauge is then adjusted, so that the gauge will make the desired run without hitting at either end, and then the marker is adjusted. As both the rate of filtration and loss of head are zero under these conditions, it is only necessary to set the markers to read zero on the gauges to adjust them. The gates can then be opened for regular operation, and the readings on the gauges will be correct. It is necessary to use wires which are light, flexible, and which will not stretch. At first, piano wire, 0.4 mm. in diameter, was used, and was well adapted to the purpose, except that it rusted rapidly. Because of the rusting it was found

necessary to substitute another wire, and cold-drawn copper wire, 0.6 mm. in diameter, was used with fair results. Stretching is less serious than it would otherwise be, as the correctness of the adjustment can be observed and corrected readily every time a filter is out of service.

From the lower chambers in the regulator houses the water flows through gates to the pipe system leading to the pure-water reservoir. Drain pipes are also provided which allow the water to be entirely drawn out of each filter, should that be necessary for any reason, and without interfering with the other filters, or with the pure-water reservoir.

The outlets of the filters are connected in pairs, so that filtered water can be used for filling the underdrains and sand of the filters from below prior to starting, thus avoiding the disturbance which results from bringing dirty water upon the sand of a filter not filled with water.

Laboratory Building. –The scientific control of filters is regarded as one of the essentials to the best results, and to provide for this there is a laboratory building at one end of the central court between the filters and close to the sedimentation basin, supplied with the necessary equipment for full bacterial examinations, and also with facilities for observing the colors and turbidities of raw and filtered waters, and for making such chemical examinations as may be necessary. This building also provides a comfortable office, darkroom and storage room for tools, etc., used in the work.

Pure-Water Reservoir.—A small pure-water reservoir, 94 ft. square, and holding about 600 000 galls., is provided at the filter plant. The construction is similar to that of the filters, but the shapes of the piers and vaulting were changed slightly, as there was no necessity for the ledges about the bottoms of the piers and walls; while provision is made for taking the rain water, falling upon the vaulting above, to the nearest filters instead of allowing it to enter the reservoir. The floor and roof of the reservoir are at the same levels as those of the filters.

Pure-Water Conduit.—The filtered water is taken from the pure-water reservoir to the present pumping station through 7 913 ft. of 48-in. pipe. For 5 450 ft. the pipe is laid under the Erie Canal, and for 1 837 ft. through Montgomery Street, with an average cut of 22 ft The pipe is not under pressure, and is made of mild open-hearth steel plates, $\frac{5}{16}$ in. thick, rolled by the Carnegie Steel Company, at Home-

FIG. 1.—INTERIOR OF A FILTER: DRAIN, GRAVEL AND SAND LAYERS.

FIG. 2.—INTERIOR OF A FILTER, READY FOR USE.

stead, Pa. The pipe was made by the Carroll-Porter Boiler and Tank Company, of Pittsburg, and both plates and pipes were inspected by Stowell & Cunningham, of Albany.

Concrete Backing.—Pipe of this thickness is not stiff enough to withstand the earth pressures in the deep cut in Montgomery Street, without being badly deformed, and is not heavy enough to be safe from the danger of floating in the canal, should the water be removed from the pipe for any reason. Concrete was used to support the sides of the pipe in the deep cut and to weight it under the canal. The amount of concrete required for these purposes was considerable, and the Board decided to use a further amount in order to surround the pipe entirely. This makes a concrete pipe with a minimum thickness of 6 ins. outside of the steel pipe for practically the whole distance, capable of supporting the earth, and able itself to serve as a conduit even if the steel pipe should be removed entirely, although in that case it would not be thoroughly water-tight. For 567 ft. on hard clay bottom, the concrete on the bottom was omitted, the natural material being probably equivalent to the concrete. For about 300 ft. at the upper end, in shallow cut and where the pipe is readily accessible, the concrete was also omitted.

The hydraulic gradient of the pipe is 1 in 1 000, and the actual slope is 1 in 1 000 from the pumping station to a point where the depth is limited by the bed of the canal, the top of the pipe being always at least 4 ft. below the nominal bottom of the canal, as required by the canal authorities. It is then level until near the upper end, outside of the canal, where it rises rapidly to the pure-water reservoir.

In passing under the Patroons Creek sewer the canal authorities required that the line should leave the canal and pass under the sewer at one side, returning to the canal afterward, the object being to prevent draining the canal in case of accident to the sewer as a result of the work under it. The section out of the canal was 230 ft. long, and that part of it under the sewer was done in tunnel and below tide level, and was accomplished without accident or injury to the sewer. The entire trench under and near the sewer was back-filled with concrete.

Tightness of Work.—The specifications provided for testing each joint of the pipe under pressure as it was laid. Difficulties were found in carrying this out, and in order to prevent delay to the work, which

would have resulted in serious embarrassment, owing to the necessity of filling the canal on May 1st, this test was suspended on part of the line. In place thereof, the pipe was maintained empty after the canal was filled, and all joints were caulked on the inside until perfectly water-tight, and there was no measurable leakage from the canal into the pipe.

Coating.—The pipe was coated by dipping in asphalt, and, after caulking tight on the inside, all imperfections in the coating, due to caulking or otherwise, were covered with melted asphalt in connection with a naphtha lamp. Where the spots were not too large the asphalt on the sides came together when softened by the flame and covered the spot completely without the addition of new material. Where the uncovered patches were large this was not possible. The place was first heated, then melted asphalt was applied and thoroughly heated and melted until it incorporated itself with the old asphalt on the edges.

The greatest difficulty was experienced in repairing breaks in the coating directly on the bottom of the pipe; although these were not serious, owing to the fact that all men who worked therein were required to wear rubbers, and thus the damage done to the coating was slight. Repairs were made by building dams of cotton waste on each side of the defective place and sponging out the water, after which the plates could be heated by a naphtha lamp and repaired in the usual way.

Air Vents.—There are two considerable depressions on the line of the pipe, one under the Bridge Street drain and one under the Patroons Creek sewer. To prevent the air from obstructing the flow of water, the summits on either side of the Bridge Street drain were connected by a 3-in. pipe with expansion joints, going over the top of the sewer and allowing the air to pass by the depression without obstruction even when the pipe is nearly filled with water.

At the Patroons Creek sewer 3-in. pipes are connected with the summits on each side, going up in the manholes to a point above the hydraulic gradient of the water, and are simply left open to the air. To prevent the entrance of dirt, etc., a half-turn neck is screwed on the top, and in the outlet, facing downward, a bushing is put in, reducing the size of the hole, and making it impossible to put in any object which would obstruct the pipe.

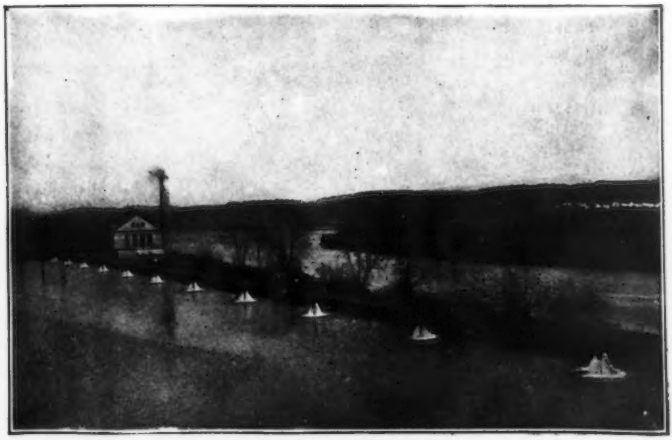


FIG. 1.—SEDIMENTATION BASIN, PUMPING STATION AND OUTLETS.

FIG 2.—CENTRAL COURT, SHOWING SAND-WASHER, DIRTY SAND, ETC.

Connections with Quackenbush Street Pumping Station.—At the lower end, connection is made with the pumping station through a rectangular brick chamber, where the flow of water can be controlled by a 48-in. gate. From this chamber the water is admitted by sluice gates to each of the three wells supplying the Allis pumps, and also to the old pump well. The entrance of water from the river was cut off by digging up the old tunnel, and building a manhole on it, in one side of which was inserted a 36-in. flange pipe and a standard 36-in. gate. The arrangement is such as to cut off the entrance of river water effectively. The gate can be opened at any time, however, if required by any emergency. The gate is accessible, and can be examined for tightness at any time by shutting off the water from the filters and lowering the water in the pump wells. Leakage is further prevented by the fact that the water in the pump wells is normally higher than the water in the river, and the tendency of leakage is outward and not inward.

Cement.—In the construction of the filters and sedimentation basin 30 000 bbls. of Atlas Portland cement were used. Iron Clad Portland cement was used in some parts of this work, and also exclusively on the pumping station and on the pure-water conduit, 8 000 or 9 000 bbls. of it being used in all. Several hundred barrels of other brands of cement were used at times when neither Atlas nor Iron Clad could be obtained promptly. No Rosendale cement was used on any part of the filters, nor in the lower part of the pumping station. On the superstructure of the regulator houses, pump house and laboratory, Rosendale cement and lime were used.

Building Sand.—All the building sand was obtained from the river by dredging, and was screened and washed by machinery. It was of the same general character as the filter sand, but had a higher uniformity coefficient and was not as clean.

Ballast for Concrete.—Gravel, obtained from the river by screening and washing, was used for the most part, but broken stone was used on various parts of the work. Sometimes the materials were used separately, but often they were mixed. The mixture was most satisfactory in every way, making a stronger and more economical concrete than either gravel or broken stone by itself.

Concrete.—The concrete for the filters was mixed by machinery in cubical boxes, 5 ft. cube, and the amount mixed was about 1.6 cu. yds.

at a time. The proportions of mixing were not fixed by the contract, but were left to the discretion of the engineer as the work progressed, and the cement was paid for separately. The usual proportions of mixing were as follows: One barrel of Portland cement, weighing 380 lbs., and nominally assumed to occupy 3.8 cu. ft.; three times this volume of sand, weighing on an average about 90 lbs. per cubic foot; and five times this volume of gravel or ballast, weighing about 100 lbs. per cubic foot, and having an average of 40% of voids. On an average for the whole work 1.26 barrels of cement were used for each cubic yard of concrete, as allowed to the contractors. Actually, the volume of concrete exceeded slightly the nominal dimensions in many cases, and the cement, reckoned on all the concrete, would be slightly less than the above figure. The discrepancies, however, were not large. The greatest rate of placing concrete on the filters was about 3 700 cu. yds. per month, and, substantially, this rate was maintained for three months.

In placing concrete around, and especially under, the 48-in. steel pipe, difficulty was found in placing that which was made with broken stone. Concrete made from gravel proved much more suitable for this purpose, and a bent rammer facilitated getting it under the pipe. Before the bent rammer was introduced, some difficulty was experienced in getting the contract sections. Afterward they were gotten easily and without trouble.

Brick Work.—All the brick work, except that in the superstructures, was of vitrified paving brick. The brick was not specified, but the specifications required brick absorbing not more than 12% of water by weight. The local brick-makers were unwilling to take the trouble to make brick hard enough to meet this requirement, and the contractors decided finally to use a second-quality paving brick. This was larger than ordinary brick, averaging 8.37 x 3.62 x 2.75 ins., and it was necessary to change the size of the piers in the filters from 20 to 21 ins., the spans of the vaulting and floor arches being reduced to correspond. These changes the contractors were allowed to make, and, in consideration of the superior quality of the brick, they were allowed an amount corresponding to the increased volume of the masonry thereby involved, although this masonry was not believed to be necessary for the stability of the structures. The bricks were regular and uniform in shape, and their use resulted in very satisfac-

tory work. The absorption ranged from 1 to 11%, and averaged 4% by weight.

The mortar used was uniformly 1 part of Portland cement to 3 parts of sand, and in a few cases, where cracks appeared and the masonry was broken, the breaks were through the bricks and not through the joints, although the bricks were extremely hard and strong. The cement was paid for separately, and about 0.80 barrel per cubic yard was used, no deduction being made for ordinary loss and waste. The greatest quantity of brick work laid in one month was 1 100 cu. yds.

Weight on Foundations.—The weight of the finished concrete was about 150 lbs. per cubic foot, as determined by tests. The brick work was computed to weigh 135 lbs. per cubic foot. The weight of the soil filling over the vaulting is estimated at 100 lbs. per cubic foot. Each of the piers in the filters, by itself, weighs 4 300 lbs. The total weight carried by the piers is about 11 tons per square foot, with the soil nearly dry. When the soil is wet, or covered with snow and ice, the weight is increased somewhat.

On the assumption that the inverted concrete arches distribute the weight of the piers over the whole area of the bottom, the weight on the foundations, of all the masonry and the earth cover, but not including the filtering material, amounts to 444 lbs. per square foot, and with the filtering material in place and with water to the nominal flow line, this weight is increased to 1 304 lbs. per square foot.

Assuming the weight of the cross-walls to be distributed on the whole width of the monolithic concrete blocks under them, the weight of the masonry, with the earth above, but without the filter sand or water, amounts to 755 lbs. per square foot, and with the sand in position and water to the flow line, to 1 415 lbs. per square foot. The excess weight under the cross-walls thus amounts to 311 lbs. per square foot with the filter empty, and to 111 lbs. per square foot with everything in position.

The foundation was generally on stiff clay capable of carrying much larger loads than the actual ones, but for a small part of the way shale was encountered. It is doubtful if there is any arch action in the floor, in which case the bulk of the weight of the piers is carried on a small area under and near the base, but the arch is there, so that if there is any tendency to settlement at any point it will come into action and

carry the weight. At one place the underlying clay was soft. Apparently, it was the channel of a stream, the position of which had been changed by the Erie Canal, and which was now filled with softer material. The area was so small as not to make it worth while to lower the general elevation of the structures, and extra foundations were provided. These were made by putting concrete, mixed in the proportion of 1: 5: 10, in the form of a wall, from hard bottom up to the ordinary foundation under the walls, and blocks of the same material, 5 ft. square, from the hard bottom up under each pier. These special foundations were put in first, the rest of the material graded to the normal level, and then the floors put in as usual. In these cases the weights on solid foundations are rather more than a ton to the square foot.

The strains in the concrete vaulting, considered as arches, are not heavy, but are somewhat difficult of computation. It appeared probable, after the centers were struck, that the vaulting did not act as arches but as a series of cantilevers. It was put in in squares, each square having a pier for a center, and the blocks were apparently strong enough to carry the loads upon them without coming to an arch action at all. Computed as cantilevers, a tensile strain of 150 lbs. per square inch is sufficient to maintain the loads as they exist, and the strength of the concrete is certainly beyond this figure.

With cold weather, some of the joints in the concrete vaulting opened slightly, indicating the absence of arch action, but no cracks in the blocks have been observed at any point.

Cracks in Walls.—The outside walls of the filters are monolithic concrete, with an 8-in. brick lining. The cross-walls are of brick. Neither has expansion joints of any kind. With cold weather, in December, 1898, cracks were discovered in each of the cross-walls on the north half of the filter plant which was then completed. One crack was found in each wall, and in each case approximately in the middle of the wall. During the winter these cracks opened from $\frac{1}{4}$ to $\frac{3}{8}$ in.

There are also a certain number of cracks on the outside walls, all of which are shown in Fig. 13. There is a break in the continuity of the outside walls where they join the regulator houses. The regulator houses were built first, and the concrete was placed against the brick work afterward, the surface of the brick being left irregular. The brick lining was bonded in, but its 8-in. thickness was not sufficient to

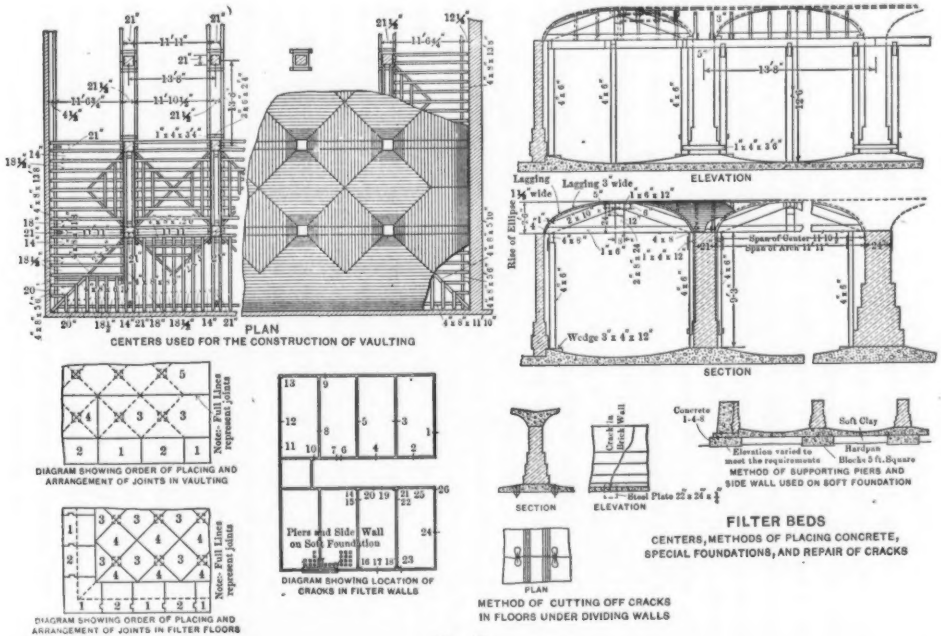

PLAN
CENTERS USED FOR THE CONSTRUCTION OF VAULTING
ELEVATION
SECTION
Lagging 1¼" wide
Lagging 3" wide
Rise of Ellipse
Span of Centers 11'10½"
Span of Arch 11'11"
Wedge 3" x 4" x 12"
DIAGRAM SHOWING ORDER OF PLACING AND ARRANGEMENT OF JOINTS IN VAULTING
Note:- Full Lines represent Joints
DIAGRAM SHOWING ORDER OF PLACING AND ARRANGEMENT OF JOINTS IN FILTER FLOORS
Piers and Side Wall on Soft Foundation
DIAGRAM SHOWING LOCATION OF CRACKS IN FILTER WALLS
SECTION
ELEVATION
Crack in Back Wall
Steel Plate 22" x 24" x ½"
PLAN
METHOD OF CUTTING OFF CRACKS IN FLOORS UNDER DIVIDING WALLS
Concrete 1-4-8
Soft Clay
Hardpan
Elevation varied to meet the requirements
Blocks 3 ft. Square
METHOD OF SUPPORTING PIERS AND SIDE WALL USED ON SOFT FOUNDATION
FILTER BEDS
CENTERS, METHODS OF PLACING CONCRETE, SPECIAL FOUNDATIONS, AND REPAIR OF CRACKS

FIG. 13.

withstand any heavy strain. The walls pulled away from the regulator houses at these points in eight cases, breaking the brick work, although there was no evidence of settlement. The cracks are absolutely without significance, as the clay filling on the outside is quite water-tight. The cracks in the outside walls are also unimportant, for the same reason. Where the outside walls cracked, the crack went approximately in a straight line from top to bottom through both brick and concrete, without following any joints in the concrete wall.

The cracks in the cross-walls were of more importance, for it is possible that unfiltered water might enter them above the sand and follow down through them and enter the gravel and underdrains below without filtration. This action might all take place on one side, or the water might enter the wall above on one side and leave it below on the other. This was rendered more likely, as the floors cracked at the same places and drew apart slightly, and it was actually found that, when the water was on one side of the wall only, it passed through the crack and up through the floor on the other side, some distance away from the wall. To cut this off, a hole was cut in the concrete near the wall, rather more than 2 ft. long and 8 ins. wide, with the ends widened as shown in Fig. 13. The concrete at this point was about 1 ft. thick. A steel plate $\frac{1}{4}$ in. thick and 2 ft. square was placed in the middle of this hole, and driven down until its top was flush with the top of the concrete. It thus projected about 1 ft. into the clay below, and the material was then so hard that the plate had to be severely pounded to get it into position. The hole was then filled with concrete. The steel plate is to serve as an expansion joint. If the crack opens further in the future, the concrete block will break again, approximately at the same place as the original crack, and will slip on the steel plate, the plate remaining across the crack to shut off any possible communication. Any water coming through the wall must thus come to the surface of the floor before reaching the plate, and, to prevent it from getting into the underdrains, the gravel is kept back for 5 ft. at this point, and the sand comes directly to the floor. The water on leaving the crack must then pass through at least 5 ft. of sand before it reaches the underdrains. This will insure, first, a tolerably good purification of such water; and second, if the water is dirty, a gradual clogging up and diminishing of the carrying power of the sand at this point and the final stopping of the leak. In any

event, it will be impossible for an impure water to reach the underdrains. The upper parts of the cracks, which were comparatively unimportant, and were accessible at all times, were caulked with oakum to prevent the passage of water above the sand.

These cracks appear to be clean temperature cracks, with hardly any evidence of settlement. The strength of the wall is such that, with one end free, with the temperature changes, it would pull or shove the wall over the clay without causing other cracks. The only cause of further cracks would be settlement, and this is not regarded as probable. To provide against it, however, as a possible contingency, and also to prevent the possibility of water passing down between the walls and the sand, the gravel is kept 2 ft. away from the walls all the way around, so that in case cracks occur at any points and water passes through them, it will have to pass through 2 ft. of sand. With one crack in each wall, which is virtually an expansion joint, it is not regarded as probable that other cracks will occur which will result in any openings in the floor.

Six cracks were caused by the frost in January and February, 1899. The south part of the filters was left in an uncompleted condition, and, with severe weather, the frost raised the walls in some places as much as 0.2 ft. With warmer weather the walls went back to their proper levels, but the cracks did not close entirely, and some of the brickwork was taken down, while other cracks were caulked with cement.

Without counting the slight openings at the corners of the regulator chambers, where the concrete met the brickwork, nor the six cracks caused by lifting from frost, there were twelve cracks in the whole of the work, and, as the total length of wall was 4 753 ft., there was, on an average, about one crack to each 400 ft. of wall.

Contractors' Plant.—The contractors for the filters and sedimentation basin installed a very elaborate overhead cable-carrier system for the transportation of materials to all parts of the work. This consisted of two trestles 730 ft. apart and over 900 ft. long, between which stretched four cables, each capable of carrying a load of 3 tons, at a height above all the structures on the ground, except the office and regulator houses. These cables were attached to carriages which ran on I-beams on the tops of the trestles, and power was conveyed to both ends by a system of rope drives, so that the cables could be

moved in one direction while the travelers upon the cables were moved in another direction at right angles to it. The trestles for the contractors' plant are shown in Figs. 1 and 2, Plate XXX, and in Fig. 1, Plate XXXI, and also in some of the other views. Fig. 1, Plate XXXI, also shows a skip for carrying concrete, with the carriage upon a cable. The installation of this apparatus required much longer than was anticipated, and delayed the completion of the work very much.

The system was extremely convenient, but its carrying capacity was less than was anticipated, particularly when motion in both directions was required. It was found better after a while to use the carriers, as a rule, in one direction only, and a double-track railroad was built near one of the trestles, which passed the concrete mixer and the gravel screens. Skips were moved on this railroad on trucks, received the concrete and gravel and ran to points opposite the places where the materials were to be used. The skips were then lifted from the trucks by the carrier system and carried to the required places. In this way the lateral motion of the carriers was used only occasionally, as the point at which work was being done changed. The work was so arranged that concrete or gravel was delivered in substantially the same line at one time.

Capacity of Plant and Means of Regulation.

The various filters have effective filtering areas of from 0.702 to 0.704 acre, depending upon slight differences in the thickness of the walls in different places. For the purpose of computation, the area of each filter is taken at 0.7 acre. The nominal rate of filtration is taken as 3 000 000 galls. per acre daily, at which rate each filter will yield 2 100 000 galls. daily, and, with one filter out of use for the purpose of being cleaned, seven filters normally in use will yield 14 700 000 galls. The entrances and outlets are all made of sufficient size, so that rates 50% greater than the foregoing are possible. The capacities of the intake, pumping station and piping are such as to supply any quantity of water which the filters can take, up to an extreme maximum of 25 000 000 galls. in 24 hours. The pure-water conduit from the filters to Quackenbush Street is nominally rated at 25 000 000 galls. per 24 hours, after it has become old and somewhat tuberculated. In its present excellent condition it will carry a larger quantity.

At the pumping station at Quackenbush Street there are three Allis

pumps, each capable of pumping 5 000 000 galls. per 24 hours. In addition to the above there are the old reserve pumps with a nominal capacity of 10 000 000 galls. per 24 hours, which can be used if necessary, but which require so much coal that they are seldom used. For practical purposes the 15 000 000 galls. represents the pumping capacity of this station and also the capacity of the filters, but the arrangements are such that in case of emergency the supply can be increased to 20 000 000 or even 25 000 000 galls. for a short time.

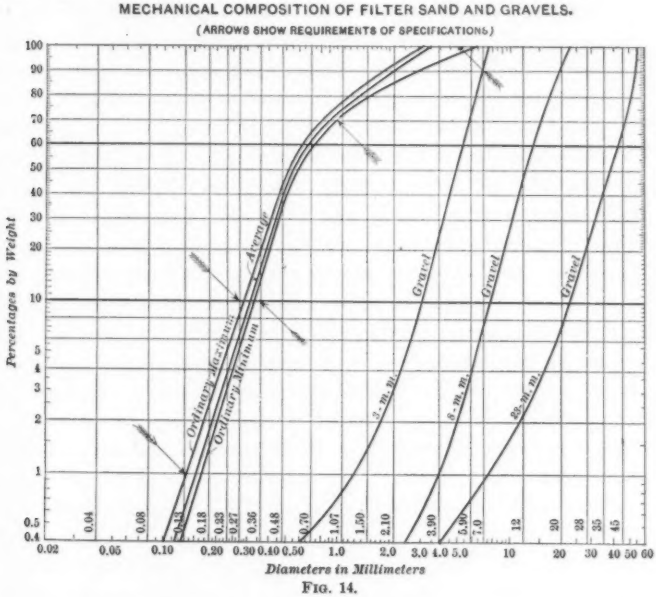


FIG. 14.

The water is pumped through rising mains to reservoirs holding 37 000 000 galls., not including the Tivoli low-service reservoir, which is usually supplied from gravity sources. The reservoir capacity is such that the pumping can be suspended at Quackenbush Street for considerable periods if necessary, and in practice it has been suspended at certain times, especially on Sundays. The amount of water required is also somewhat irregular. The drainage areas supplying the gravity reservoirs are much larger, relatively, than the reservoirs, and at flood periods the volume of the gravity supply is much greater than that

which can be drawn in dry weather. Thus it happens that, at certain seasons of the year, the amount of water to be pumped is but a fraction of the nominal capacity of the pumps, and at these times it is possible to shut the pumps down for greater lengths of time.

Capacity of Pure-Water Reservoir.—The storage capacity provided between the filters and the Quackenbush Street pumps is comparatively small, namely, 600 000 galls., or one hour's supply at the full nominal rate. A larger basin, holding as much as one-third or one-half of a day's supply, would be in many respects desirable in this position, but the conditions were such as to make it practically impossible. The bottom of the reservoir could not be put lower without deepening and increasing greatly the expense of the conduit line. On the other hand, the flow line of the reservoir could not be raised without raising the level of the filters, which was hardly possible upon the site selected. The available depth of the reservoir was thus limited between very narrow bounds, and to secure a large capacity would have necessitated a very large area, and consequently a great expense. Under these circumstances, and especially in view of the abundant storage capacity for filtered water in the distributing reservoirs, it was not deemed necessary to provide a large storage, and only so much was provided as would allow the pumps to be started at the convenience of the engineer, and give a reasonable length of time for the filters to be brought into operation. For this, the pure-water reservoir is ample, but it is not enough to balance any continued fluctuations in the rate of pumping.

Method of Regulating and Changing the Rate of Filtration.—With all the Allis pumps running at their nominal capacity, the quantity of water required will just about equal the nominal capacity of the filters. When only one or two pumps are running, the rate of filtration can be reduced. With the plant operating up to its full capacity, the water level in the pure-water reservoir will be below the level of the standard orifices in the filter outlets. When the rate of pumping is reduced, if no change is made in the gates controlling the filter outlets, the water will gradually rise in the pure-water reservoir and in the various regulator chambers, and will submerge the orifices and gradually reduce the head on the filters, and consequently the rates of filtration, until those rates equal the rate of pumping. In case the pumping is stopped altogether, the filters will keep on delivering at gradually

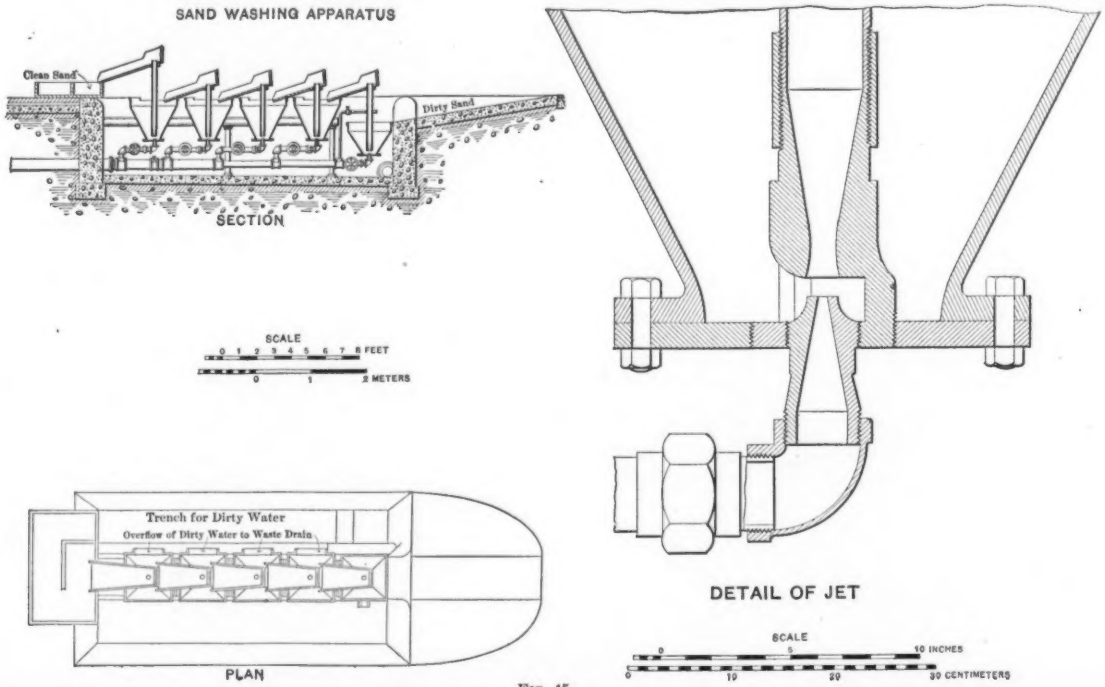

SAND WASHING APPARATUS
Clean Sand
Dirty Sand
SECTION
SCALE
0 1 2 3 4 5 6 7 8 FEET
0 1 2 METERS
Trench for Dirty Water
Overflow of Dirty Water to Waste Drain
PLAN
DETAIL OF JET
SCALE
0 5 10 INCHES
0 10 20 30 CENTIMETERS

FIG. 15.

reduced rates until the water level in the pure-water reservoir reaches that of the water on the filters.

When the pumps are started up, after such stoppage or reduced rate of pumping, the water levels in the pure-water reservoir and in the gate chambers will be lowered gradually, and the filters will start to operate at first with extremely low rates which will increase gradually until the water is depressed below the orifices, when they will again reach the rates at which they were last set. The regulators during all this time will show the rate of filtration on each filter, and, if any inequalities occur which demand correction, the gates on the various outlets can be adjusted accordingly.

The arrangement, in this respect, combines some of the features of the English and German plants. In the English plants the filters are usually connected directly with the clear-water basin, and that in turn with the pumps, and the speed of filtration is required to respond to the speed of the pumps, increasing and decreasing with it, being regulated at all times by the height of water in the pure-water reservoir. This arrangement has been subject to severe criticism, because the rate of filtration fluctuates with the consumption, and especially because the rates of filtration obtained simultaneously in different filters may be different. There was no way to determine at what rate any individual filter was working, and there was always a tendency for a freshly scraped filter to operate much more rapidly than those which had not been scraped for some time.

This led to the procedure, first formulated by the Commission of German Water-Works Engineers in 1894, and provided for in most of the German works built or remodeled since that time, of providing pure-water storage sufficient in amount to make the rate of filtration entirely independent of the operation of the pumps. Each filter was to be controlled by itself, be independent of the others, and deliver its water into a pure-water reservoir lower than itself, so that it could never be affected by back-water, and so large that there would never be a demand for sudden changes in the rate of filtration.

This procedure has given excellent results in the German works; but it leads oftentimes to expensive construction. It involves, in the first place, a much greater loss of head in passing through the works, because the pure-water reservoir must be lower than the filters, and the cost of the pure-water reservoir is increased greatly

because of its large size. The regulation of the filters is put upon the attendants entirely, or upon automatic devices, and regulation by what is known as "responding to the pumps" is eliminated.

More recently, the German authorities have shown less disposition to insist rigidly upon the principles advanced in 1894. In a compilation of the results of several years' experience with German water filters, Dr. Pannwiz,* makes a statement of particular interest, of which a free translation is as follows:

"Most of the German works have sufficient pure-water reservoir capacity to balance the normal fluctuations in consumption, so that the rate of filtration is at least independent of the hourly fluctuations in consumption. Of especial importance is the superficial area of the pure-water reservoir. If it is sufficiently large there is no objection to allowing the water level in it to rise to that of the water upon the filters. With very low rates of consumption during the night the filters may work slowly and even stop, without damage to the sediment layers when the stopping and starting take place slowly and regularly, because of the ample reservoir area.

"The very considerable fluctuations from day to day, especially those arising from unusual and unforeseen occurrences, are not provided for entirely by even very large and well-arranged reservoirs. To provide for these without causing shock, the rate of filtration must be changed carefully and gradually, and the first essential to success is a good regulation apparatus."

"Responding to the pumps" has a great deal to recommend it. It allows the pure-water reservoir to be put at the highest possible level, it reduces to a minimum the loss of head in the plant, and yet provides automatically, and without the slightest trouble on the part of the attendants, for the delivery of the required quantity of water by the filters at all times. If the filters are connected directly to the pumps there is a tendency for the pulsations of the pumps to disturb their operation, which is highly objectionable, even if the pumps are far removed; and this exists where filters are connected directly to the pumps, and a pure-water reservoir is attached to them indirectly. By taking all the water through the pure-water reservoir and having no connection except through it, this condition is absolutely avoided, and the pull on the filters is at all times perfectly steady.

Much has been said as to the effect of variation in the rate of filtration upon the efficiency of filters. Experiments have been made

*"*Arbeiten aus dem Kaiserlichen Gesundheitsamte*," Vol. xiv., p. 260.

at Lawrence and elsewhere which have shown that, as long as the maximum rate does not exceed a proper one, and under reasonable regulations, and with the filter in all respects in good order, no marked decrease in efficiency results from moderate fluctuations in rate. There is probably a greater decrease in efficiency by stopping the filter altogether, especially if it is done suddenly, than by simply reducing the rate. The former sometimes results in loosening air bubbles in the sand, which rise to the surface and cause disturbances, but this is not often caused by simple change in rate.

On the whole, there is little evidence to show that, within reasonable limits, fluctuations in rate are objectionable, or should be excluded entirely, especially in such cases as at Albany, where arrangements to prevent them would have resulted in very greatly increased first cost. The inferior results sometimes obtained with the system of "responding to the pumps" as it existed in earlier works, and still exists in many important places, undoubtedly arises from the fact that there is no means of knowing and controlling the simultaneous rate of filtration in different filters, and that one filter may be filtering two or three times as fast as another, with nothing to indicate it.

This contingency is fully provided for in the Albany plant. The orifices are of such size that even with a filter just scraped and put in service, with the minimum loss of head, with the outlet gate wide open, and with the water level in the pure-water reservoir clear down; that is, with the most unfavorable conditions which could possibly exist, the rate of filtration cannot exceed 5 000 000 or 6 000 000 galls. per acre daily, or double the nominal rate. This rate, while much too high for a filter which has just been cleaned, is not nearly as high as was possible, and in fact actually occurred in the old Stralau filters at Berlin, and in many English works; and, further, such a condition could only occur through the gross negligence of the attendants, because the rate of filtration is indicated clearly at all times by the gauges. These regulating devices have been specially designed to show the rate with unmistakable clearness, so that no attendant, however stupid, can make an error by an incorrect computation from the gauge heights. It is believed that the advantage of clearness by this procedure is much more important than any increased accuracy which might be secured by refinements in the method of computation,

which should take into account variations in the value of the coefficient of discharge, but which would render direct readings impossible.

In designing the Albany plant the object has been to combine the best features of German regulation with the economical and convenient features of the older English system, and filters are allowed to respond to the pumps within certain limits, while guarding against the dangers ordinarily incident thereto.

Results of Operation.

The filters were designed to remove from the water the bacteria which cause disease. They have already reached a bacterial efficiency of over 99%, and it is expected that their use will result in a great reduction in the death rate from water-borne diseases in the city. They also remove a part of the color and all of the suspended matters and turbidity, so that the water is satisfactory in its physical properties.

The filters have reached, with perfect ease, their rated capacity, and on several occasions have been operated to deliver one-third more than this amount; that is to say, at a rate of 4 000 000 galls. per acre, daily.

The filters are operated by George I. Bailey, M. Am. Soc. C. E., Superintendent of the Albany Water-Works, whom the writer hopes will present further particulars concerning the cost and results of operation.

Cost of Construction.

The cost of the filtration plant complete is shown by Table No. 3. As some of the accounts are not yet closed, a few of the items, designated by stars (*) are estimated, and are subject to slight change with the closing of all the accounts.

The filters, sedimentation basin and pure-water reservoir are connected in such a way as to make an exact separation of their costs impossible; but, approximately, the sedimentation basin cost $60 000, the pure-water reservoir $9 000, and the filters $255 000. The sedimentation basin thus cost $4 100 per million gallons capacity; and the filters complete, cost $45 600 per acre of net filtering area, including all piping, office and laboratory building, but exclusive of land and engineering.

TABLE No. 3.—Approximate Cost of Filtration Plant Complete.

Land		$8 290.00
Pumping Station:		
Pumping machinery, boilers, etc.	$22 000.00	
Intake	3 800.00	
Pump well, gates, screens and foundations	6 285.00	
Pumping station building	12 167.00	
Chimney	1 540.00	
Venturi meter	1 560.00	
Extra work and minor items	2 393.00*	
		49 745.00*
Filters, Sedimentation Basin and Pure-Water Reservoir:		
Preliminary draining	$1 956.71	
70 672 cu. yds. excavation, at (average) $0.3079 +	21 761.64	
16 040 cu. yds. rolled clay and gravel embankment, at $0.52	8 340.80	
22 851 cu. yds. silt and loam filling, at $0.15	3 427.65	
23 439 cu. yds. general filling rolled, at $0.18	4 219.02	
12 550 cu. yds. puddle, at $0.715	8 973.25	
1 775 cu. yds. gravel for lining, at $0.85	1,508.75	
2 257 sq. yds. split stone lining, at $0.82	1 850.74	
11 737 cu. yds. concrete in floors, at $2.31	27 112.47	
7 792 cu. yds. concrete in vaulting, at $3.85	29 999.20	
3 147 cu. yds. all other concrete, at $2.13	6 703.11	
4 382 cu. yds. brick work, at $8.125	35 603.75	
31 715 barrels Portland cement, at $1.935	61 368.53	
7 281 cu. yds. filter gravel, at $1.05	7 645.05	
36 488 cu. yds. filter sand, at $1.00	36 488.00	
Cast-iron pipes and specials, placed, including placing gates	21 841.25	
Gates and valves	6 714.23	
Vitrified pipe, complete	7 153.32	
672 filter manhole covers, at $4.40	2 956.80	
8 sand-run fixtures, at $407.50	3 260.00	
8 regulator houses, at $862.24	6 897.92	
1 office and laboratory	4 881.00	
Vitrified brick paving	2 158.00	
Iron fence about court	1 704.00	
Extra work and all minor items	9 692.01	
		324 217.20
Conduit and Connections with Quackenbush Street Pumping Station:		
7 913 ft. 48-in. steel pipe, at $4.50	$35 608.50	
24 218 cu. yds. excavation at (average) $0.855 +	20 715.60	
3 144 cu. yds. concrete, at $5.00	15 720.00	
Gates and connections with pumping station	3 680.00	
Sewer and railroad crossings, sheeting, and all other items	10 914.12*	
		86 638.22*
Engineering, inspection, printing, laboratory equipment, minor construction, etc.		31 000.00*
Total approximate cost of work		$499 890.42*

The preliminary estimate of cost submitted to the Board, February 8th, 1897, amounted to $478 000. The work will actually cost, in round numbers, $22 000, or 4.6% more than the preliminary estimate.

* Estimated.

The preliminary estimate, and the actual costs by more important divisions, are as follows:

	Preliminary estimate, Feb. 8, 1897.	Approximate actual cost.
Land	$10 000	$8 290
Pumping station and intake	34 000	49 745
Filters and sedimentation basin, with piping	327 000	324 217
Pure-water conduit and connection, with Quackenbush Street pumping station	64 000	86 638
Engineering and contingencies	43 000	31 000
Total	$478 000	$499 890

The excess in the cost is in the pumping station and conduit line. The cost of the conduit line was increased by surrounding it with concrete, which was not included in the preliminary estimate, and also by certain changes in the location required by the canal authorities. The pumping station also was made more elaborate and expensive than was contemplated in the preliminary estimate, but the intake was shortened. Otherwise, the work was executed substantially as first planned.

ACKNOWLEDGMENT.

The general plan and location of the plant were first conceived by the Superintendent of Water-Works, George I. Bailey, M. Am. Soc. C. E., and the successful execution is largely due to his efforts. The members of the Water Board, and especially the Construction Committee, have followed the work in detail closely and personally, and their interest and support have been essential factors in the results accomplished. In the designs and specifications for the pure-water conduit the writer is greatly indebted to Emil Kuichling, M. Am. Soc. C. E., and also for most valuable suggestions relative to the performance of this part of the work. To William Wheeler, M. Am. Soc. C. E., of Boston, the writer is indebted for advice upon the vaulting and cross-sections of the walls, and these matters were submitted to him before the plans were put in final shape. All the architectural designs have been supplied by Mr. A. W. Fuller, of Albany. W. B. Fuller, M. Am. Soc. C. E., as Resident Engineer, has been in direct charge of the work, and its success is largely due to his interest in it and the close attention which he and the assistant engineers have given it.

DISCUSSION.

Mr. Bailey. GEORGE I. BAILEY, M. Am. Soc. C. E.—Two filters were put in service July 27th. Four more were started July 28th. All of these ran until August 9th, and three of them continued until August 12th. They were started with the hope of continuing, but the conditions were unfavorable in that the water was pumped direct to the filters, as the sedimentation basin was not ready for use; the court between the filters, in which scraped sand was to be deposited, washed and stored, was neither leveled nor paved; and the water in the river was roiled and disturbed by the contractors' operations, and particularly with the wash-water from the sand being prepared for the remaining two filters. The run of the filters was, therefore, stopped and not again commenced until September 5th, since which time their operation has been continuous.

COST OF OPERATION.

The work was organized as follows:

Filter operation:	10 laborers,	at	$1.50 per day.
	1 foreman	"	2.75 "
	1 watchman	"	1.50 "
	1 chemist	"	1 000.00 per year.
Pumping Station:	3 engineers	"	75.00 per month.
	3 firemen	"	60.00 "

The working day is eight hours for laborers, engineers and firemen, and over-time is paid for at the rates named. Occasionally, extra help has been hired, and paid for at these rates.

The gross cost of operation, including payroll, tools which are still in use, repairs, supplies of all kinds, wash-water, etc., etc., for the period from September 5th to December 25th, inclusive, 118 days, was $6 164.94. In this time 1 470 000 000 galls. were filtered, making an average of $4.19 per million gallons delivered from the filters.

The master mechanic of the works gives the following statement from his records, as the daily cost at the pumping station:

3 engineers	at	$2.48	$7.44
3 firemen	"	1.98	5.94
3 tons coal	"	2.72	8.16
1 laborer	"	1.50	1.50
9 galls. engine oil	"	0.09	0.81
2 galls. cylinder oil	"	0.11	0.22
5 galls. kerosene oil	"	0.10	0.50
5 lbs. waste	"	0.07	0.35
Steam packing, sheet rubber, soap, soda, mops, cloths, etc.			6.58
Total			$31.50

Mr. Bailey.

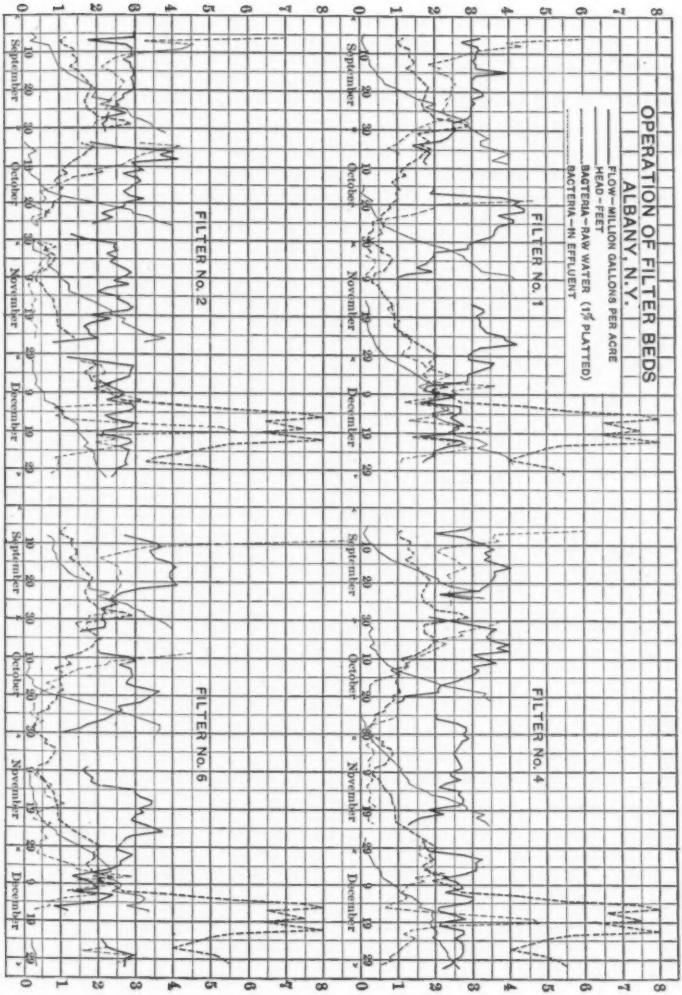


Fig. 16.

Mr. Bailey. This makes the average cost of pumping $2.52 per million gallons received from the filters, and leaves $1.67 as the cost of operating the filters, including laboratory work. The cost of scraping, wheeling out, washing and replacing sand for the actual number of hours, and exclusive of superintendence, laboratory work, lost time, tools, etc., is $1.19 per million gallons treated.

TABLE No. 4.—GALLONS FILTERED AND HOURS EMPLOYED IN SCRAPING FILTERS AND WHEELING OUT SCRAPED SAND.

Filter No.	Service.	Gallons filtered. (5% to be added for error.)	Scraping.		Wheeling Out.	
	Hours.		Hours.	Square yards.	Hours.	Barrows.
1.....	266.45	22 409 000	43	Each scraping covers an area of 3 402 sq. yds.	86	983
1.....	791.55	59 164 000	50		80	813
1.....	559.25	41 457 000	45		81	789
1.....	1 015.50	72 635 000	42		88	932
2.....	291.00	26 581 000	46		115	1 027
2.....	638.00	49 571 000	50		86	962
2.....	534.00	44 822 000	47		79	771
2.....	685.00	45 520 000	41		83	886
3.....	342.75	32 377 000	57		91	1 028
3.....	639.00	49 296 000	49		75	875
3.....	579.20	42 296 000	44		82	726
3.....	877.00	63 406 000	46		92	1 067
4.....	355.10	32 357 000	52		124	1 119
4.....	470.20	44 290 000	56		91	942
4.....	548.00	45 757 000	49		81	763
4.....	718.50	50 717 000	46		81	878
5.....	664.60	53 359 000	51		78	820
5.....	556.70	40 428 000	27		86	874
5.....	840.00	60 459 000	43		83	802
6.....	312.70	28 826 000	53		109	1 007
6.....	618.70	55 263 000	51		78	836
6.....	547.00	41 133 000	44		76	808
6.....	932.00	65 457 000	44		88	920
7.....	631.00	38 506 000	42		69	835
8.....	361.20	33 006 000	56		105	1 105
8.....	513.00	40 497 000	53		76	987
8.....	591.00	50 529 000	50		79	805
8.....	807.20	56 150 000	40		78	819
28.....	16 685.60	1 286 268 000	1 317	95 256	2 420	25 179

The filters have been cleaned 26 times in all, up to December 25th, or a little more than three times each. The total amount of sand treated, as measured when replaced, was 850 cu. yds. From the books of the foreman, the following records are taken:

Scraping.—88 452 sq. yds. = 18.3 acres; time, 1 227 hours = 67 hours per acre.

Wheeling Out Scraped Sand.—23 180 barrows, 2 235 hours = 27.3 barrows per cubic yard = 0.38 cu. yd. per hour. The average length of wheel, going and coming, was 600 lin. ft. = 1.18 miles per man per hour.

Washing.—18 262 barrows, 2 068 hours, 21.5 barrows per cubic yard = 0.41 cu. yd. per hour.

From experiments made by John H. Gregory, Jun. Am. Soc. C. E., who was Resident Engineer for Mr. Hazen during the completion of

the work, the speaker is informed that the volume of water for washing the sand varied from 12 to 14 times the volume of sand washed. In the cost of operation the volume has been estimated at 15, at a cost of $0.04 per thousand gallons. Mr. Bailey.

Refilling.—18 550 barrows, 1 630 hours, 21.8 barrows per cubic yard = 0.52 cu. yd. per hour. This work was chiefly done by extra labor. The average depth of scraping was about $\frac{3}{8}$ in., computed from the total quantity of sand replaced and the area scraped.

During the periods covered by these scrapings, the filters yielded 1 212 000 000 galls., an average of 66 600 000 galls. per acre between scrapings. This includes the first run of the filters, when the unnaturally turbid water already mentioned was pumped directly on the beds.

Bacteria.

Table No. 5 shows the weekly averages of the bacterial removal:

TABLE No. 5.

Week ending	Bacteria Per Cubic Centimeter.		Percentage of removal.
	Unfiltered.	Filtered.	
September 9	11 545	608	94.8
16	14 083	306	97.8
23	17 480	273	98.5
30	22 600	259	98.8
October 7	18 766	250	98.7
14	11 783	178	98.5
21	9 933	85	99.1
28	4 733	84	98.4
November 4	6 091	56	99.1
11	5 141	46	99.1
18	7 950	69	99.1
25	11 090	79	99.3
December 2	19 240	109	99.4
9	20 016	198	99.1
16	57 700	142	99.7
23	66 000	327	99.5
30	48 940	215	99.6

Table No. 6 shows in detail the result obtained from each filter each day. It will be noted that the percentage of removal is high, and that the bacterial count in the filtered water is low.

Color.

The average color of the Hudson River water corresponds to 0.50 to 0.60 on the platinum scale, and about 40% of this color is removed from the water by the filters.

Turbidity.

In periods of freshet the water is very turbid. The highest turbidity reached since the operation of the filter was in December, when the raw water showed 0.60. The effluent then contained 0.008. Generally the raw water runs about 0.035, all of which is removed. The platinum-wire standard is used.

Mr. Bailey. TABLE No. 6.—ALBANY FILTER PLANT.—BACTERIAL REMOVAL BY FILTERS.

Day of month.	Raw Water	1		2		3		4		5		6		7		8		Pure Water.	
	Bacteria.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.
SEPTEMBER.																			
1	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
2	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
5	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	800	....
6	11 500	600	94.8	700	93.9	500	95.7	600	94.8	3 700	67.8	....	....	....	....	....	....	800	93.0
7	10 200	392	96.2	331	96.8	397	96.3	361	96.5	1 800	82.4	....	....	....	....	420	95.9	508	95.0
8	10 860	432	96.1	457	95.8	363	96.7	355	96.7	913	91.6	100	89.9	....	....	437	96.0	571	94.7
9	13 700	337	96.4	431	96.8	381	97.2	372	97.3	731	94.7	873	93.7	....	....	541	96.8	567	95.9
10	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
11	13 200	256	98.1	265	97.9	353	97.3	220	98.3	433	96.7	336	97.5	....	....	194	98.5	420	96.8
12	14 700	231	98.4	243	98.3	320	97.8	207	98.6	440	97.0	269	98.0	....	....	214	98.5	294	98.9
13	14 300	182	98.7	....	....	321	97.8	228	98.4	402	97.2	243	98.3	....	....	220	98.5	284	98.0
14	12 400	218	98.2	211	98.3	....	....	256	98.0	550	95.6	205	98.4	....	....	197	98.4	257	97.9
15	14 700	206	98.6	237	98.4	....	....	273	98.1	362	97.5	228	98.4	....	....	200	98.6	286	98.1
16	15 200	242	98.4	247	98.4	....	....	286	98.1	375	97.5	251	98.3	....	....	216	98.6	298	98.2
17	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
18	17 100	256	98.5	276	97.4	....	....	252	98.6	360	97.9	261	98.5	....	....	231	98.7	289	98.3
19	18 900	247	98.7	263	98.6	....	....	241	98.7	345	98.2	250	98.7	....	....	221	98.8	273	98.6
20	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
21	17 600	243	98.6	251	98.6	....	....	249	98.6	336	98.1	261	97.5	....	....	232	98.7	265	98.5
22	17 100	231	98.6	243	98.6	625	96.3	241	98.6	312	98.2	254	98.6	....	....	245	98.6	276	98.4
23	16 700	236	98.6	232	98.6	351	97.9	237	98.6	289	98.2	246	98.5	....	....	231	98.6	261	98.4
24	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
25	17 400	221	98.7	224	98.7	316	98.2	246	98.6	261	98.5	231	98.7	....	....	219	98.7	250	98.6
26	19 300	231	98.8	237	98.8	320	98.3	240	98.8	275	98.6	239	98.8	....	....	244	98.7	267	98.6
27	20 200	241	98.8	229	98.9	276	98.6	....	....	261	98.7	233	98.8	....	....	237	98.8	257	98.7
28	27 100	197	99.3	205	99.2	267	99.0	....	....	247	99.1	241	99.1	....	....	....	....	261	99.0
29	29 300	172	99.4	191	99.3	240	99.2	....	....	215	99.3	176	99.4	....	....	....	....	244	98.2
30	22 800	258	98.8	189	99.2	236	98.4	375	98.3	237	98.9	179	99.2	....	....	700	96.9	278	98.8
OCTOBER.																			
1	17 000	134	99.3	....	....	215	98.7	360	97.9	155	99.1	137	99.2	....	....	390	97.7	267	98.4
2	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3	17 200	109	99.4	....	....	194	98.1	265	98.5	....	....	162	99.1	....	....	420	97.6	230	98.7
4	19 400	98	99.5	313	98.4	180	99.1	278	98.6	....	....	....	....	....	....	390	98.0	250	98.7
5	21 000	71	99.7	421	98.0	142	99.3	191	99.1	....	....	....	....	....	....	340	98.4	240	98.9
6	19 200	105	99.5	360	98.2	150	99.2	230	98.8	640	96.7	....	....	....	....	280	98.6	264	98.7
7	18 800	102	99.5	325	98.3	140	99.2	219	98.8	560	97.0	....	....	....	....	260	98.6	250	98.7
8	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
9	15 100	....	....	275	98.2	110	99.3	170	98.9	260	98.3	450	97.7	....	....	220	98.5	239	98.4
10	11 300	....	....	265	97.7	120	98.9	143	98.7	240	97.9	340	97.0	....	....	156	98.6	233	97.9
11	12 100	....	....	197	98.4	90	99.3	125	99.0	206	98.3	231	98.1	....	....	144	98.8	170	98.6
12	13 200	....	....	210	98.4	83	99.4	130	99.0	212	98.4	220	98.3	....	....	170	98.7	178	98.7
13	8 200	....	....	140	98.4	60	99.3	119	98.7	165	98.0	155	98.2	....	....	110	98.8	135	98.5
14	10 800	....	....	115	98.9	39	99.6	106	99.0	135	98.8	130	98.8	....	....	87	99.2	115	98.9
15	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
16	9 800	....	....	72	99.3	36	99.6	39	99.6	86	99.1	91	99.1	....	....	34	99.7	79	99.2
17	10 200	....	....	45	99.6	50	99.5	27	99.7	71	99.3	60	99.4	....	....	35	99.7	50	99.5
18	10 400	....	....	53	99.5	72	99.3	26	99.8	32	99.7	86	99.2	....	....	25	99.8	46	99.6
19	11 000	460	95.8	61	99.7	....	....	24	99.8	74	99.3	54	99.5	....	....	43	99.6	160	98.5
20	8 800	198	97.8	50	99.4	....	....	27	99.7	121	98.6	37	99.6	....	....	41	99.5	76	99.1
21	9 400	200	97.8	24	99.8	....	....	70	99.3	32	99.7	30	99.7	....	....	33	99.7	101	98.9
22	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
23	6 900	135	98.1	66	99.0	141	98.0	35	99.5	35	99.5	27	99.6	361	94.8	15	99.8	125	98.2
24	7 000	70	99.0	24	99.7	125	98.2	....	....	36	99.5	30	99.6	471	93.3	26	99.6	120	98.3
25	3 900	66	98.3	22	99.6	70	98.2	105	97.3	36	99.1	16	99.6	250	93.6	....	....	70	98.2
26	4 200	69	98.4	33	99.2	63	98.5	87	97.9	30	99.3	26	99.4	125	97.0	....	....	75	98.2
27	3 500	59	98.3	....	....	64	98.2	36	99.0	24	99.3	54	98.5	100	97.2	64	98.2	58	98.4
28	2 900	62	97.9	....	....	44	98.5	20	99.3	14	99.5	36	98.8	165	94.3	58	98.0	57	98.0
29	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
30	2 500	27	98.9	31	98 8	18	99.3	14	99.4	....	....	17	99.3	150	94.0	16	99.4	37	98.5
31	4 500	24	99.5	68	98.5	26	99.4	34	99.3	....	....	....	....	165	96.3	34	99.3	68	98.5

TABLE No. 6—(*Continued*).

NOVEMBER.

Day of month.	Raw Water	1		2		3		4		5		6		7		8		Pure Water.	
	Bacteria.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.	Bacteria.	Per cent. removed.
1	6 350	23	99.6	96	98.5	24	99.6	32	99.5	....	....	....	....	175	97.1	22	99.6	53	99.2
2	5 700	31	99.4	53	99.1	23	99.6	14	99.8	93	98.4	....	....	150	97.4	25	99.6	51	99.1
3	8 500	15	99.8	72	99.2	29	99.7	31	99.6	140	98.4	....	....	L	....	27	99.7	57	99.3
4	9 000	43	99.5	54	99.4	22	99.8	38	99.6	120	98.7	....	....	172	98.1	97	98.9	69	99.2
5																			
6	7 750	34	99.6	43	99.5	19	99.8	22	99.7	61	99.2	....	....	95	98.8	18	99.8	59	99.2
7	6 900	25	99.6	57	99.2	26	99.6	27	99.6	128	98.2	....	....	115	98.3	17	99.8	52	99.3
8	4 000	16	99.6	26	99.4	20	99.5	L	....	90	97.8	....	....	76	98.1	18	99.6	48	98.8
9	3 800	19	99.5	25	99.4	28	99.3	11	99.7	40	99.0	50	98.7	88	97.7	15	99.6	40	99.0
10	3 400	....	....	26	99.2	19	99.5	22	99.4	36	98.9	28	98.2	120	96.5	17	99.5	35	99.0
11	5 000	....	....	16	99.7	14	99.7	33	99.3	62	98.8	35	99.3	104	97.9	15	99.7	44	99.1
12																			
13	6 200	....	....	20	99.7	12	99.8	17	99.7	41	99.3	76	98.8	65	98.9	27	99.6	45	99.3
14	7 350	....	....	26	99.7	17	99.8	25	99.7	38	99.5	57	99.2	89	98.8	35	99.5	57	99.2
15	8 200	....	....	33	99.6	29	99.7	28	99.7	45	99.5	55	99.3	96	98.8	37	99.6	65	99.2
16	8 200	98	98.8	25	99.7	....	....	23	99.7	31	99.6	63	99.2	119	98.1	27	99.7	87	98.6
17	8 500	75	99.1	27	99.7	....	....	23	99.7	40	99.5	85	99.0	92	98.9	32	99.6	75	99.1
18	9 250	85	99.1	31	99.7	120	98.7	41	99.6	36	99.6	112	98.8	....	....	23	99.8	83	99.2
19																			
20	9 200	107	98.8	15	99.8	135	98.5	21	99.8	28	99.7	40	99.6	....	....	18	99.8	87	99.1
21																			
22	9 500	95	99.0	35	99.6	120	98.7	23	99.8	19	99.8	24	99.8	....	....	17	99.8	85	99.1
23	10 750	115	98.9	36	99.7	105	99.0	40	99.6	28	99.7	73	99.3	....	....	28	99.7	89	99.2
24	12 000	130	98.9	32	99.7	122	99.0	....	....	30	99.8	57	99.5	....	....	32	99.7	101	99.2
25	14 000	140	99.0	32	99.7	150	98.9	....	....	55	99.6	48	99.6	....	....	29	99.8	112	99.2
26																			
27	17 300	135	99.2	....	....	124	99.2	175	99.0	33	99.8	64	99.7	....	....	57	99.8	115	99.3
28	19 400	118	99.4	....	....	108	99.4	160	99.2	35	99.8	44	99.8	....	....	27	99.9	97	99.5
29	21 000	115	99.4	....	....	100	99.5	....	....	25	99.9	50	99.8	....	....	39	99.8	99	99.5
30	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

DECEMBER.

1	18 600	165	99.1	153	99.2	115	99.4	159	99.2	20	99.9	33	99.8	....	....	....	....	107	99.4
2	19 900	179	99.1	210	99.1	185	99.1	187	99.1	56	99.7	64	99.7	....	....	....	....	130	99.3
3																			
4	16 800	245	98.6	223	98.7	256	98.5	195	98.8	110	99.3	136	99.2	....	....	153	99.1	185	98.9
5	18 100	215	98.8	187	98.9	235	98.7	173	99.0	105	99.4	145	99.2	....	....	225	98.8	195	98.2
6	18 500	190	99.0	210	98.9	225	98.8	230	98.8	....	....	185	99.0	....	....	245	98.6	200	98.9
7	23 000	360	98.5	197	99.2	225	99.1	144	99.4	....	....	290	98.8	....	....	265	98.9	219	99.1
8	19 300	245	98.7	128	99.3	212	99.9	172	99.1	....	....	145	99.2	....	....	360	98.2	182	99.1
9	23 500	270	99.2	140	99.4	276	98.8	128	99.5	....	....	246	99.0	....	....	340	98.6	210	99.1
10																			
11	27 000	120	99.6	320	98.8	115	99.6	110	99.6	233	99.1	116	99.6	....	....	310	98.8	152	99.5
12	44 000	213	99.5	285	99.4	117	99.7	128	99.7	249	99.4	198	99.6	....	....	276	99.4	192	99.6
13	55 000	225	99.6	88	99.8	169	99.7	116	99.8	255	99.6	110	99.8	....	....	256	99.5	163	99.7
14	75 000	249	99.7	112	99.9	64	99.9	85	99.9	216	99.7	62	99.9	....	....	211	99.7	96	99.0
15	80 200	185	99.8	87	99.9	182	99.8	68	99.9	308	99.6	72	99.9	....	....	198	99.8	115	99.9
16	65 000	130	99.8	136	99.8	210	99.7	165	99.7	378	99.4	30	99.9	....	....	147	99.8	131	99.8
17																			
18	75 000	350	99.5	525	99.3	450	99.4	460	99.4	575	99.2	....	....	Lo	st	560	99.2	435	99.4
19	64 000	350	99.5	570	99.1	490	99.2	475	99.3	520	99.2	....	....	315	99.5	470	99.3	450	99.3
20	71 000	137	99.8	195	99.7	243	99.7	210	99.7	320	99.5	....	....	312	99.6	350	99.5	275	99.6
21	80 000	268	99.7	250	99.7	325	99.6	135	99.8	360	99.5	....	....	450	99.4	330	99.6	310	99.6
22	56 000	233	99.6	183	99.7	260	99.5	114	99.8	310	99.4	....	....	475	99.2	305	99.5	291	99.5
23	50 000	310	99.4	255	99.5	257	99.5	146	99.7	175	99.6	....	....	Lo	st	150	99.7	205	99.6
24	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
25																			
26	40 000	115	99.7	84	99.8	....	....	103	99.7	117	99.7	225	99.4	315	99.2	140	99.7	162	99.6
27	45 000	110	99.7	98	99.8	....	....	95	99.8	100	99.8	160	99.6	340	99.2	90	99.8	180	99.6
28	51 000	....	....	95	99.8	490	99.0	78	99.8	150	99.7	280	99.5	370	99.3	119	99.8	250	99.5
29	53 700	....	....	100	99.8	370	99.4	85	99.8	141	99.7	290	99.5	325	99.4	115	99.8	255	99.5
30	55 000	....	....	80	99.9	380	99.3	55	99.9	112	99.8	250	99.5	280	99.5	125	99.8	230	99.5
31	.....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

Typhoid Fever.

Mr. Bailey. The reason for building the filters was the sewage pollution of the Hudson River and the large death rate from typhoid fever. The average number of deaths from this cause for the nine years ending with 1898 was 85 per annum. During the four months in which the filters have been in operation seven deaths from this cause have been reported. For the corresponding months of the nine years ending with 1898 the average number has been 24. The deaths from this cause have thus been reduced in the ratio of 24 to 7, and one of these seven was in a family which did not use city water.

Mr. W. B. Fuller. William B. Fuller, M. Am. Soc. C. E.—It has occurred to the speaker that it would interest the members if a few words were added concerning the details of construction, of the Albany Filter Plant, which present special features.

The sedimentation basin is situated close to the river bank and lies almost wholly in embankment above the natural surface of the ground. The embankments were constructed of the best available materials, and with great care, so as to minimize any effects of after-settling; but, for tightness, reliance was placed on a 16-in. layer of puddle, which covered the entire bottom of the basin and extended up the sides to 1 ft. above high-water level. For a distance of 5 ft. below high-water level, or to below the lowest level to which the basin is likely to be drawn in winter, the puddle is set back 2 ft. 10 ins. from the face so as to be beyond injury from frost, and is covered with a 2-ft. layer of gravel and 10 ins. of blue limestone paving. In all other places the puddle is faced with 6 ins. of concrete, to prevent mechanical injury to its surface and to present an easily cleansed and smooth surface for the interior of the basin.

The materials of the puddle were equal parts of clay and a sandy gravel containing about 40% sand and 60% gravel of all sizes to about 1 in. in diameter. Clean gravel of a size from ¼ to 1 in. was tried, but was not a success. These materials were mixed in a screw-paddle, continuous mixer, such as is often used for mixing concrete, water being added and the mixing continued until all the clay lumps were softened and the clay had penetrated thoroughly all the interstices of the gravel.

In this plastic condition the puddle was placed in position in 6-in. layers over a larger surface and left to dry out. In the process of drying, a large number of shrinkage cracks appeared throughout the mass, but by thorough ramming these cracks were closed and the entire mass consolidated. This process was continued for each of the three layers. The idea was, that with the shrinkage cracks closed and the excess water removed, there was no further tendency to shrinkage, and any water then entering the puddle would expand it and close any remaining cracks. Some of this puddle stood uncovered on 1 on 1½

Mr. W. B. Fuller.

slopes for over a year, exposed to rain and frost, but no cracking or deterioration of any kind was noticed, and it remained as hard as hard-pan earth.

The paving of the upper sides of the sedimentation basin is of blue limestone blocks, rather larger than the usual size, being about 10 to 15 ins. deep, 15 to 36 ins. long and 8 to 20 ins. wide. Two masons and one helper together would lay about 16 sq. yds. per day, and the labor cost of laying the stone and gravel, including the teaming of the materials about 800 lin. ft., was $0.72 per square yard.

The gravel used in the joints and under the paving was the waste from the filter-sand screen. It was perfectly clean, of sizes from $\frac{1}{4}$ to to 1 in., the largest amount being about $\frac{3}{8}$ in., and made an ideal material for the purpose.

The piping about the filters and sedimentation basin was all of light-weight cast-iron pipe, with hub and spigot, lead-caulked joints. The entire system was laid at the same time, the trenches and all bell holes being left open, and the joints made water-tight under a hydrostatic pressure of 50 lbs. per square inch, before making any refill.

All the concrete used in the floors, walls and vaulting, amounting to 22 100 cu. yds., was machine-mixed, especial care being taken with the mixing and placing. A mixed sand and gravel was obtained from the river by dredging, and was brought to and deposited near the mixers, and then washed and screened into three sizes—sand, gravel and tailings. The sand was of very good quality, sharp and clean. The gravel was of irregular, smooth-edged stone from $\frac{1}{4}$ to $1\frac{1}{2}$ ins. in diameter, but varying greatly as to average size from day to day, sometimes fine and sometimes coarse. The tailings were passed through a stone crusher and broken to sizes ranging from $\frac{3}{4}$ to $2\frac{1}{2}$ ins. in diameter.

Mechanical analyses of the sizes of these three materials were made daily or oftener, and from these analyses the proper proportions of a mixture of the three to give a minimum number of voids was deduced. The total quantity of the three materials used with a unit quantity of cement was always constant, but by thus varying the proportions of the ingredients themselves, a very uniform concrete product was obtained, independent of the variation in the average size of any particular ingredient. The proportions ordinarily followed were 1 part of cement, 3 parts of sand, 4 parts of gravel, and 1 part of crushed stone.

The mixing was done in a cubical mixer, to which a measured quantity of water could be introduced after the materials had been thoroughly mixed dry. With the apparatus as used at Albany, the concrete was always mixed properly and of the right consistency; half an hour's attention to it, when starting, insuring uniformity for all day unless there were great weather changes, in which case the quantity of water had to be changed more frequently.

Mr. W. B. Fuller.

The transportation of the concrete from the mixer and its deposition in place in the work, which has been described by the author, was ideal, from an engineering point of view. From the time of taking the concrete from the mixer until it was put in place 800 ft. distant the interval of 5 minutes was not uncommon, and the average time did not exceed 15 minutes.

The cost of labor, coal, and for measuring quantities, and mixing, loading, transporting and tamping concrete, during an average of about three months of the best organization, was about as follows:

Measuring, mixing and loading....	$0.20	per cubic yard.
Transporting by rail and cables....	0.12	" "
Laying and tamping on vaulting...	0.14	" "
Laying and tamping floors and walls, including setting forms...	0.22	" "

These prices do no not include general superintendence, profit or cost of machinery.

The design of the vaulting, as has been stated by the author, is in the form of an elliptical groin with dimensions as follows: span, 12 ft.; rise, 2 ft. 6 ins.; thickness at crown, 6 ins.; thickness over center of pier, 2 ft. 6 ins. This work was figured for strength according to the theory of the arch, assuming that brick masonry and concrete spandrel filling were to be used. The material actually used was Portland cement concrete laid as a monolith, with the pier in the center, and, as thus constructed, it is exceedingly doubtful if there is any arch action whatever in the structure. From recent observations and from some tests made on small models the speaker believes that such a groined arch acts in tension as an inverted pyramidical dome. If this is the case, the depression over the piers could be increased materially and the cost of the vaulting reduced. Even as constructed, the adoption of the 6-in. depression over each pier saved 1 053 cu. yds. of concrete, which would have cost $6 560 at contract prices.

The speaker wishes to controvert an impression, which seems to be prevalent, that permanent masonry vaulting is very expensive, several recent estimates placing the cost of covered filters at from 50% to 100% in excess of the cost of open filters. The total extra cost of the vaulting at Albany, including extra thickness of floors, piers, roof drains, manholes, sand-run entrances, earth covering, etc., at the contract prices, was approximately $0.315 per square foot of area inside the walls, or $13 700 per acre, while the total cost of the filters was about $45 600 per acre; that is, the vaulting represents only about 30% of the cost of the filters.

The lumber of the centering for the vaulting was of spruce for the ribs and posts, and of hemlock for the lagging, which was 1½ and 3 ins. wide and 1 in. thick. The entire centering for two filters was formed by machinery, the ribs put together to a template, and the lagging all

Mr. W. B. Fuller.

sawed to proper lengths and bevels. For the first two filters the centers were put together in place, and were so constructed that when struck they would come down in sections and could be moved forward and used in the corresponding bay of the next filter.

The total cost of the centering was approximately as follows:

Building centers covering 62 560 sq. ft.

Labor—

Foreman,	435 hours,	at $0.35	$ 152.25	
Carpenters,	4 873 "	0.225	1 096.42	
Laborers,	3 447 "	0.15	517.05	
Painters,	577 "	0.15	86.55	
Teaming,	324 "	0.40	121.60	
			$1 973.87	

Materials—

Lumber, 313 000 ft., B. M.	$5 700.00		
Nails, 3 700 lbs.	111.00		
Tar, 8 bbls.	24.00		
		5 835.00	
			$7 808.87

Taking down, moving and putting up centers covering 196 660 sq. ft.

Labor—

Foreman,	2 359 hours,	at $0.35	$ 825.65	
Carpenters,	12 766 "	0.225	2 872.35	
Laborers,	24 062 "	0.15	3 609.30	
Team,	430 "	0.40	172.00	
			$7 479.30	

Materials—

Lumber, 3 000 ft., B. M.	$60.00		
Nails, 3 000 lbs.	90.00		
		$150.00	
Total		$7 629.30	
			7 629.30
Total approximate cost			$15 438.17

The total area centered was 259 220 sq. ft., and the average cost per square foot was 6 cents, to which should be added general superintendence and a reasonable profit.

As bearing upon the need of a covering, for protection against frost, the following records for Albany are quoted. The temperature of the air varies from + 98° to — 18° Fahr. per annum, the average temperature for the year being + 45° Fahr. These figures are the result of 22 years' observation by the local weather bureau. The river is frozen over from December 16th to March 19th, an average length

Mr. W. B. Fuller.

of 93 days, as shown by an average of the records of 75 years. The longest time in any one season in which the river has remained frozen over was 117 days.

There are other advantages, besides the prevention of the formation of ice, which enable the covered filter to be operated at a lower cost for maintenance than the open filter, a few of which are as follows:

By preventing the formation of algæ growths.

By maintaining the temperature of the water practically even, thus keeping the friction of the sand constant, as by maintaining uniform conditions, improvement of the filtrate results.

By preventing the action of the heat and the direct rays of the sun in summer from baking the surface during the operation of scraping, thereby occasioning the removal of a greater thickness of sand.

By keeping the surface from disturbance by wind and thus allowing more efficient sedimentation.

By preventing the fall of rain on the surface during cleaning, which causes compacting of the surface and necessitates re-raking.

By preventing the fall of snow on the surface during cleaning, which causes the removal of a greater thickness of sand.

By preventing the increase in cost of washing sand containing leaves and algæ growths.

By admitting of uninterrupted scraping of the filter during all kinds of weather.

As the extra cost of vaulting is only about $13 700 per acre, which by added knowledge can possibly be reduced to $10 000 per acre in another plant, and which amount at 3% interest represents only $300 to $400 per year, it is seen that in many places other considerations besides that of protection from ice would lead to the use of covered filter beds.

Mr. Maignen.

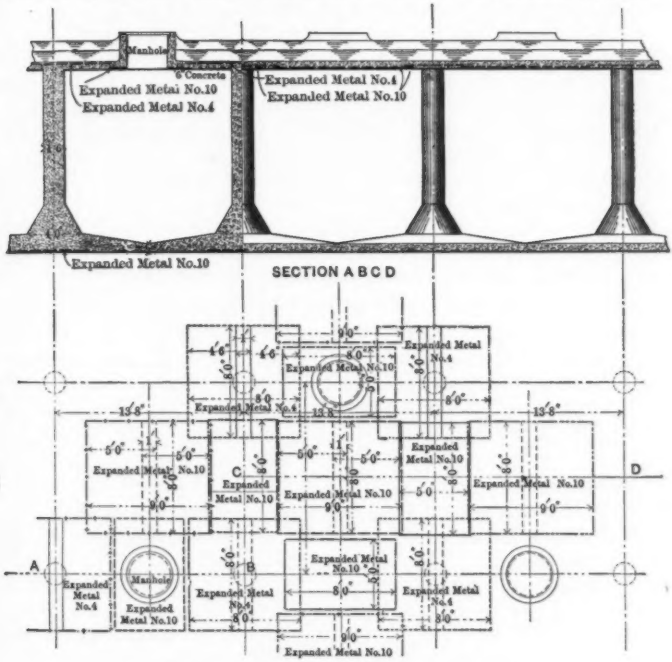
P. A. MAIGNEN, Assoc. Am. Soc. C. E.—The construction of the filters at Choisy-le-Roi, near Paris, is interesting. Some of the walls of the filters are very thin, being only 2.4 ins.; and their construction with what is termed in the United States "expanded metal" and concrete has been quite satisfactory. The company which operates these filters has built filter beds 120 ft. square, and others 60 ft. square. They found the smaller beds better for solidity and also because of the greater convenience in cleaning.

In the Albany plant the sand-washing apparatus is not covered. The speaker supposes that it is the intention to have it covered, in order that the washing of the sand may not be delayed by freezing weather.

The provision made for preventing the raw water, which may go down through or along the retaining walls, from mixing in an unpurified state with the filtered water, is interesting. It would seem better that such provision be made at the top of the sand bed instead of at the bottom.

Mr. Hill. GEORGE HILL, M. Am. Soc. C. E.—The paper is so completely what it should be, it describes so completely the way in which the work was done, its cost and its effect, that the speaker does not wish to be understood as offering any criticism in calling attention to a few details wherein the cost of the work might have been reduced, without in any way impairing its efficiency.

Referring to Fig. 7, it might be well to note that 8-in. beams are too shallow to be used with a projection of 5 ft., as they would be apt to



PLAN SHOWING DISTBIBUTION OF EXPANDED METAL

FIG. 17.

deflect so much as to crack the concrete, admitting moisture and therefore hastening decay. Fifteen-inch beams used in the grillage would have had five times the strength, with but two and one-half times the weight, would have had practically no deflection, a thicker section to resist rust, and, being spaced wider, would have given more room to pack the concrete between them.

The steel track used by the speaker, and described in a previous

Mr. Hill. paper,* would have been particularly applicable for the handling of dirty sand, as mentioned on page 264, and would have been found to be inexpensive. The speaker has used it for coal and ash tracks carrying loads of 500 lbs. very satisfactorily.

The principal feature wherein a saving could have been effected was in the floor and covering of the filtration basins. At the time when estimates were being made, one of the prospective bidders consulted with the speaker regarding the construction proposed and was advised to suggest the plan shown in Fig. 17.

It is probable that the lack of any published data regarding the action of steel and concrete in combination, and especially the lack of knowledge regarding the resistance of continuous slabs supported at a number of points, lead, in a measure, to the rejection of this advice, if it ever was presented by the bidder. Numerous experiments made by the speaker confirm him in the belief that the carrying capacity of a slab supported at a number of points and made continuous over them, is, for a portion of the slab included between one set of supports, four times as great as that of a slab of the same sectional area and dimensions supported at two opposite edges, or, for the sections proposed, 650 lbs. per square foot, safe working load.

The relative costs for one bay are as follows:

As executed:		
5.8 cu. yds.	vaulting	$22.35
8.72 "	flooring	20.15
1.24 "	brick work	10.08
	Total	$52.58
As proposed:		
10 cu. yds.	in roof slab, supporting column, floor and foundation	$23.10
	Centering	7.47
	Expanded metal	10.60
	Total	$41.17

Saving 22 per cent.

It will be observed that the centering is far more simple, and the placing of the concrete less costly. The ramming of the concrete could be done with a roller instead of by hand, thus effecting a further saving. None of these points has been taken into account in the above comparison. The capacity of the filter could have been increased by raising the upper limit of the filling, or the cost decreased by reducing the height of the pier and decreasing the depth of the excavation.

Transactions, Am. Soc. C. E., Vol. xxxix, p. 620.

Mr. Miller. A. M. MILLER, M. Am. Soc. C. E.—There appears to be some misapprehension as to the cost of concrete. The author states the price per cubic yard paid to the contractor, but the City of Albany furnished the cement. The cost mentioned by Mr. Hill, for the construction of the filters, is exclusive of the cost of cement. The author calculates that 1¼ bbls. of cement per cubic yard were required, and this, at 1.93½ per barrel, would add $2.42 to the cost per cubic yard. This must be borne in mind when examining the estimates. These questions, however, as to details of costs, strength of materials, etc., can be readily answered.

The speaker has heard that the Board of Health of New York City has stated that eventually the whole of the Croton water supply, some 300 000 000 galls. per day, must be filtered. The handling of such a large quantity will be a very serious question. The speaker is now considering the filtration of a supply of 60 000 000 galls. per day, and is glad to listen to those who have had some experience in these matters.

Information is needed as to methods of examining water, the quantity or thickness of sand required for filtering, the rate of filtration, etc., and Mr. Hazen's paper is very instructive in regard to these matters.

Mr. Bailey's statements in reference to the percentage of bacteria removed are interesting, though the speaker does not believe in expressing the results in that way. For instance, even though 95% of the bacteria may be removed by filtration, yet, possibly 700 bacteria come through, and thus the percentage method is misleading.

The cost of the filters per acre is an important item. From the statements of cost in the paper it is found that this was about $45 600. In the recent report of the Board of Experts on the water supply of Philadelphia, the cost is stated as about $37 000 per acre. Is the difference in cost due to the use of covered and open filters? If so, what is the estimated cost of the vaulting per acre?

Mr. Hering. RUDOLPH HERING, M. Am. Soc. C. E.—Albany has a raw water supply, as well as the filtered supply, and these two supplies are mixed and stored in an open reservoir. Mr. Bailey's statement in reference to the reduction of the typhoid fever death rate applies to the mixed waters. If this death rate should not be reduced as much as in other cities the filter should not be debited with the discrepancy, because raw water is added to the filtered water, and because both are stored in an open reservoir exposed to the air, dust, and other aerial contamination.

In Philadelphia it is proposed to cover all filters and reservoirs containing filtered water. The difference between the cost of the Albany filters and the estimated cost of the Philadelphia filters, is due to the difference in the prices of some of the materials, and some parts of the design. Otherwise there is no difference.

Mr. Hering. Mr. W. B. Fuller's description of the details of construction is interesting and valuable. He has pointed out very clearly the advantages of having covered, rather than open, filters, and the probable additional cost thereof. He has also pointed out the advantage of a batter on the sides to prevent the formation of seams which would allow raw water to pass through the filter more rapidly than permissible. An expedient which further helps to prevent an undue speed of the percolating water through the larger interstices necessarily formed between the sand and the smooth surface of the adjoining wall, is the transformation of this smooth surface into a sanded surface. This is done simply by first painting it with cement and then throwing sand against it. The sand, which sticks when the cement hardens, prevents the formation of interstices of excessive size.

Dr. Mason. Dr. WILLIAM P. MASON.—In the removal of the taste or odor produced by the discharges from gas-works, the Albany plant has failed, and in this, any plant must, of necessity, fail. There have been many complaints in Albany in relation to this matter, and the best way out of the difficulty seems to be to arrange with the gas company not to put any of their waste products into the water.

TABLE No. 7.—COMPARISON OF COSTS OF OPERATION OF FILTERS AT ALBANY, N. Y., WITH THOSE IN SEVERAL EUROPEAN CITIES.

Costs are based upon an 8-hour day at $1.50.

Location of Filters.	Items.	Time in man-hours per acre.	Cost.	
			Per million gallons.	Per acre.
Albany.....	Scraping dirty sand into piles.....	61.1	$0.19½	$11.45
	Wheeling out dirty sand and leveling beds.....	111.0	0.35½	20.81
	Washing sand, wheeling it back to filter and leveling the top: $1.13½ — (0.19½ + 0.35½) = $0.58½	.....	0.58½	.....
	Total cost of cleaning.....	.....	1.13½	32.26
Liverpool....	Scraping. (Labor, $0.91 for 10 hours per day).....	.....	.....	12.50 to 25.00
London..... (New River.)	Scraping and wheeling out dirty sand, costs $13.39 per acre, with labor at $0.93 for 10 hours, or, based on an 8-hour day at $1.50.....	144.0	.....	27.00
London..... (Southwark and Vauxhall.)	Scraping and wheeling sand to sand-washer costs $38.00 per acre, with labor at $0.95 for 10 hours, or, based on an 8-hour day at $1.50.....	400.0	.....	75.00
Schiedam....	Scraping and wheeling out dirty sand costs $10.44 per acre, with labor at $0.60 for 10 hours, or, based on an 8-hour day at $1.50	174.0	.....	32.62
Rotterdam...	The mean cost for filter management during 10 years has been.....	.....	$1.53	.....

The speaker, being interested in the subject, has made some experiments in reference to this flavor or odor. The English plan of filtration was a failure, likewise the mechanical filters; but the speaker has found that, after the water had been treated in a mechanical plant, the difficulty was overcome by passing the water through carbon. The simplest way, however, is to prevent the gas material from entering the water. Dr. Mason.

The figures in Table No. 7, in reference to the operation of filters, have been arranged in such a manner as to facilitate comparison with the cost of operating some of the European filter plants.

CHARLES E. FOWLER, Esq.* (by letter).—The writer has had no experience in the operation of covered filters, and, therefore, cannot be certain that there are not difficulties in their operation unknown to him. Judging, however, from his experience in the use of open filters, it would appear that the usual hindrances to successful operation had been entirely removed in the construction of the Albany plant. Indeed, it would seem that the only difficulty to be apprehended in the operation of the plant would be the tendency to place undue reliance upon the automatic appliances which, however perfect and complete, require watching. To one accustomed to battle with atmospheric conditions in operating an open filter plant in this latitude, the supervision of such a plant as described would seem a pleasant pastime. Mr. Fowler.

It is ordinarily understood that the chief object to be attained in covering a filter is to obviate the difficulties and expense arising from the action of frost, and this possibly may be the chief, but it is by no means the only, object to be sought, at least in dealing with a water having the characteristics of the Hudson River water at Poughkeepsie. The algæ growths on the sand in summer are quite as troublesome and almost as expensive as ice and frost in winter. Like ice, they can develop on an unlimited area in the same time as on a small unit, and will stop a filter and put it out of service just when it should be otherwise doing its best work. Covering, as described in this paper, will prevent the development of algæ entirely. During the summer of 1899 the filters at Poughkeepsie were scraped six times, from May 1st to October 10th, at a cost of about $70 for each scraping. Had it not been for algæ growths, three scrapings in that period would have been sufficient. The cost of the extra scrapings necessitated by the algæ growths, together with the cost of washing and replacing the additional sand removed, amounted in 1899 to more than the cost of removing ice.

There is still another evil incident to an open filter in the hot months. It is essential to the proper working of a filter that, in scraping, as little sand as possible be removed, and that the depth removed

* Superintendent and Engineer of Public Works, Poughkeepsie, N. Y.

Mr. Fowler. be as nearly uniform over the entire area as possible, about ½ in. being the ordinary depth. In the hot months, after a filter has been in use for two or three years, the surface of the sand, when exposed for scraping, and thus subjected to the rays of the sun, will bake, in the course of a few hours, to a depth of 1 or 1½ ins., or even, in extreme cases, 2 ins. It frequently happens, therefore, that in commencing to scrape a bed in the morning the normal thickness will be removed, but before the work is finished, on account of the action of the sun on the exposed surface, it may be necessary to remove three or four times the normal thickness, thus lessening the efficiency of the bed and largely increasing the expense of scraping. The writer, therefore, from his experience, would urge the covering of filters in any climate, particularly for river waters similar to those of the Hudson.

From the writer's experience it is essential that a filter should always be filled, to a short distance above the sand surface, from below. It seems impossible to admit a current of water on the dry sand so as not to wash or furrow it, and even after filling, the escape of the confined air greatly disturbs the uniform compactness. The writer, therefore, notes with pleasure the completeness of the arrangement for filling the Albany filters from below.

The writer is of the opinion that the single filters of the Albany plant have as great an area as can be operated with economy and efficiency. However great the plant to be installed, it should be composed of units no greater in area than those described. Units of lesser area may be used where desired; indeed, it is the writer's opinion that no plant, however small, should be composed of less than four distinct units of equal area, combined as in the plant under consideration.

The quantity of gravel used appears to have been reduced to a minimum. This is rendered possible by the concave form of the bottom. It may, however, be questioned if the depth over the collecting pipes, 4½ ins., is sufficient to insure, for the greatest period practicable, against sand reaching the collectors and obstructing them. When the old filter at Poughkeepsie, designed by the late James P. Kirkwood, M. Am. Soc. C. E., was opened for repairs in 1897, after having been in operation twenty-five years, sand was found all the way down to the bottom of the filter, although the original depth of stones and gravel was 4 ft.

The depth of broken stones was 2 ft. Above the stones were four courses of gravel, each 6 ins. in thickness. In the absence of actual measurement, it is believed that the mean effective size of the gravel in the upper course was but little if any greater than that in the upper course of the Albany filters, though it was evidently less carefully screened. One of the causes tending to force the sand down into the gravel was, undoubtedly, the invariable practice of filling the bed

from the surface,—there being no other means provided. The avoidance of this practice, in the Albany filters, together with the greater care in screening the gravel, will lessen the tendency of the sand to pass downward; nevertheless, the writer believes that some sand will, in time, however remote, reach the collectors, and that an additional thickness of gravel would prolong that time in a ratio greater than that of the increased thickness. It seems to the writer that about double the thickness of each grade of gravel over the top of the conductors would remove the time of possible obstruction of the collectors to a period in the future sufficiently remote to justify the additional expense of construction. Mr. Fowler.

The device for aeration, numerous small holes near the top of the vertical extension of the inlet pipes to the settling basin, would seem to require the addition of some appliance for keeping the holes clear and preventing their becoming closed by algæ and floating or suspended matter.

The devices for preventing undue loss of head or pressure upon the filters, for observing and regulating the rate of filtration, and for preventing an excessive rate, appear to be admirably adapted for their respective purposes.

The writer congratulates the author and all associated with him in the design and construction, as well as the City of Albany, upon the successful installation of a filtering plant apparently so nearly perfect in all its arrangements for successful operation.

Mr. G. W. Fuller.

George W. Fuller, Assoc. M. Am. Soc. C. E. (by letter).—This important paper, dealing with the largest plant of its kind now in operation in this country, is a valuable contribution to the subject of water purification. In many ways this plant shows the results of careful thought and of thorough studies of the experimental evidence obtained in this country, and also of the construction and operation of municipal plants in Europe.

Comparing the Albany plant with those constructed years ago in Europe for the purification of the general type of water of which the Hudson River is representative, it is found that this plant contains many improvements. It is thoroughly modern, embodying the results of the progress of the last dozen years in this particular line. For many years the construction and results of operation of the Albany plant will doubtless be studied by engineers interested in water purification.

In reading this very interesting paper there occurred to the writer a number of points of inquiry and comment, the principal of which are as follows:

Character of Hudson River Water with Reference to Turbidity and Color.—The paper deals at considerable length with the sewage pollution of the unfiltered water, but leaves the reader to his general infor-

Mr. G. W. Fuller.

mation with regard to the nature, degree and duration of turbid water which occurs in the Hudson at Albany. Obviously, this factor was of some significance in the design of the plant, for the reason that it was decided to construct a sedimentation basin. All members of this Society are doubtless familiar with the general facts that the Hudson flows through glacial drift formation and not through a clay-bearing region; that the headwaters of the river are in a mountainous country, clad in the winter with snow which melts rapidly in the early spring so as to produce freshets; and that at Albany the river is a comparatively short one. In the near future, specific information will presumably be available on this subject; but the writer desires to inquire what the general evidence now available shows as to the amount and character of suspended matters in the water during freshets; and also the frequency, intensity and duration of freshets.

It is stated at the close of the paper that the filtered water is satisfactory in appearance regarding color, although it is not stated how much color is found in either the unfiltered or filtered water. The question of how much color due to dissolved organic matters may be present in a water of satisfactory appearance is one upon which there is much difference of opinion. And it is of especial significance in connection with the type of plant adopted at Albany, because, ordinarily, it is possible by this means to remove only about one-third of the color of the applied water. While satisfactory results were doubtless obtained in this particular instance, this is, nevertheless, an interesting topic for discussion.

Filtering Materials and Underdrains.—In connection with the efficiency of the filter, the filtering materials and underdrains are of prime importance. The Albany plant, in general terms, represents the best modern theory and practice in these particulars, and it is here that this plant differs most from the older ones in Europe. Formerly it was the practice to use gravel layers much thicker than was necessary to support the sand and conduct the filtered water to the collecting pipes, and, in some instances at least, the layers were not properly graded to prevent the upper layers from settling into the lower ones. At the present time many reliable data are available to serve in making these computations. Concerning the use of the thin graded layers of gravel, there is no doubt that they conduce to both efficiency and economy. In the case of the Albany plant they appear to be worked out as finely as it is safe to adopt in practice. In fact, in the opinion of some engineers, it might be considered questionable whether, with only three grades of gravel, it is advisable to use with the finer grades such thin layers as 2 to 2.5 ins. The experience of the writer shows that ordinarily no difficulty should arise under these conditions, but that rigid inspection of the work is necessary to guard against the layers settling together. The writer desires to inquire if

any evidences have been detected of the sand passing into and through the gravel layers.

The practice of placing no gravel layers beneath the sand within a distance of 2 ft. 4 ins. of the walls of the filter is especially commendable. If this had been adopted in the older filters it would have doubtless precluded many instances of unfiltered water reaching the filtered water drains.

Filter Covers.—Although there are a number of open filters in service in the general section of the country in which Albany is located, the question of the advisability of covering these filters is too obvious to be a fitting one for discussion. The principal point, in this connection, is to note that for the first time in this country the vaulting for filter covers has been made entirely of concrete. This departure results in economy, and doubtless will be adopted in many instances in the future.

Pure-Water Reservoir and Control of Rate of Filtration.—The description and discussion of these phases of the plant are among the most interesting parts of the paper. They are unusual and unique in a number of ways, and, while not such as to be a model type under many conditions elsewhere, they appear to serve their purpose admirably in this case and to be based on sound reasoning.

Cost of Filters.—The cost of these covered filters, $45 600 per acre, exclusive of land and engineering, is much less than the general figures obtained from other and earlier plants. While there is no doubt that efficient and durable filters of this type can be built, ordinarily, much more cheaply than has been generally considered to be the case, yet the conditions for construction at Albany were usually favorable in a number of ways, as follows:

1. The filter site was a level tract of land, requiring practically no grading and no excavation other than that necessary to obtain material for the embankments.

2. Very little rock excavation was required.

3. The floor of the filters rests on blue or yellow clay, as compared with the quicksand and the made land which would be encountered in some localities.

4. The conditions, apparently, were free from complications, and required no very expensive steps relative to the exclusion of ground-water from the plant. Concerning the leakage of the filtered water, in the event of cracks in the fairly light masonry, the ground-water level would cause the loss of water to be very small, compared with conditions found elsewhere.

5. Construction materials were much cheaper at the time the Albany contracts were let, than at present.

6. The site was very favorably located with reference to securing and delivering the various materials of construction.

Mr. G. W. Fuller.

7. With open filters, heavier masonry in some respects would be required than in the case of covered filters.

In noting these points, in regard to which Albany was very fortunate, it is, of course, obvious that they do not detract from the merit of this paper on a plant which, in the writer's opinion, is entitled to great praise.

Mr. Whipple.

GEORGE C. WHIPPLE, Assoc. M. Am. Soc. C. E. (by letter).—The writer wishes to express his appreciation of the service which the Water Department of Albany has rendered to the public in the construction of the filter, so well described by Mr. Hazen. Not only will this filter prove a blessing to the citizens of Albany by the saving of lives, but it will stand as a model for American engineers and an object lesson to certain American cities which have been negligent in protecting themselves from the dangers of their polluted water supplies.

The brief period during which the Albany filter has been in operation is not sufficient to show exactly the degree of purification of the Hudson River water which will be attained permanently, but the figures presented by Mr. Bailey show that already good results are being obtained, and that the bacterial efficiency is improving steadily.

On the other hand, it has been found that there are certain things which the filter will not do. It will not remove all the coloring matter from the water. Experts realize that this is not to be expected, but the ordinary consumer does not understand why the filtered water should not be colorless. Experiments have shown that simple sand filtration is not capable of removing more than about one-half of the coloring matter from water, under favorable conditions, and that ordinarily the amount of reduction is not more than one-third or one-fourth. Mr. Bailey has stated that the color reduction at Albany thus far has been about 40%, the color of the applied water being at times as high as 0.50 or 0.60 on the platinum scale. The removal of color by a new filter is usually greater than by one which has been long in use, and it is probable that this percentage of removal cannot be always maintained. The removal of coloring matter from the Hudson River water by the sand filters at Poughkeepsie is shown by the following figures taken from analyses made at various times by Dr. T. M. Drown:

	Feb., 1891.	Nov., 1891.	Dec., 1891.	Jan., 1892.	Apr., 1894.
Color of applied water	0.233	0.15	0.60	0.38	0.30
Color of filtered water	0.19	0.10	0.65	0.40	0.25
Percentage of reduction of color	17	33	....	....	17

In the spring of 1899, the writer obtained the following results from the Poughkeepsie filter:

Color of Hudson River water	0.32
Color of tap water in Poughkeepsie	0.26
Percentage of removal of color	19

Mr. Whipple.

It has been found at Albany that sand filtration is not always effective in removing certain odors from the applied water. Professor Mason has alluded to the odor imparted to the water of the Back Channel by waste material discharged from the gas-works, and which, not being removed by the filter, caused some complaint from the consumers. This matter of odor, in water which is to be purified, should not be overlooked by engineers when considering filtration works. Inasmuch as sand filtration cannot be depended upon to remove such odors as those observed at Albany, it is essential that the applied water should be freed from them, and it is a case where prevention is easier than cure.

Many American streams receive large amounts of factory refuse, and in such cases filtration alone may not always render the water palatable. The refuse should be purified before it is allowed to enter the streams. Sometimes very large streams become affected with odors from factory wastes. The Schuylkill River at Philadelphia is a case in point. A few years ago the water in certain sections of Philadelphia acquired a disagreeable odor which resembled that of creosote as much as anything. Through the courtesy of John C. Trautwine, Jr., Assoc. Am. Soc. C. E., the writer was given the opportunity to make some observations as to the cause of this odor. Samples of water were collected in various parts of the city and examined physically and microscopically. The character of the odor showed that it was not due to microscopic organisms, and no odor-producing organisms were found in the water. The odor was apparently due to manufacturing waste, and suspicion fell upon certain paper mills a few miles above the city from which large volumes of refuse material were discharged at certain times during the day. Samples of water collected from the river had the same odor as that observed in the city, and near the mill where the refuse material was supposed to be discharged the odor was very decided. The microscopical examinations of the samples showed the presence of fragments of wood fiber in the river water and in some of the samples of tap water. The samples which contained the largest amounts of wood fiber gave in general the strongest odors. Furthermore, it was the testimony of many individuals that the odor was not of equal intensity throughout the day, this being due, apparently, to intermittent discharges from the mills.

There is one feature of the operation of the Albany filter which will be watched with interest by biologists, namely, the storage of the filtered water in an open reservoir. It has become a well-recognized principle in this country that ground-waters cannot be stored in reservoirs exposed to the light without liability to deterioration from troublesome algæ growths; and the question has already presented itself to the minds of some as to whether the water supply at Albany will not some day suffer from this cause. Time alone will tell whether

Mr. Whipple. their fears will be realized. That diatoms and other microscopic organisms will develop to some extent in the stored water is to be expected, but the experience of Lawrence and of Poughkeepsie would indicate that the chances of serious trouble from such growths are not very great. In this connection the writer desires to ask the author whether microscopical examinations of the water in the reservoir have shown as yet any tendency of the microscopic organisms to develop; whether the reservoir into which the filtered water is pumped has been recently cleaned; and, if not, whether there exists at the present time any considerable amount of sediment at the bottom of the reservoir. Experience with the reservoirs of the Brooklyn water supply, where mixed ground-water and surface water is stored in open sunlight, has shown that the deposits which form at the bottom of the reservoir have an important influence on the development of the microscopic organisms.

Allusion has been made to the growth of algæ upon the surface of open filters and to the annoyance which they cause in the operation of the filter. Some interesting studies of the growths of microscopic organisms over the sand have been made recently by Dr. Otto Strohmeyer, of Hamburg, and Dr. Ad. Kemna, of Antwerp. A brief account of their observations, with some additional studies made by the writer, may not be out of place in this discussion.

At Hamburg it has been the custom for a long time, whenever a filter-bed was scraped, to examine microscopically the surface film over the sand and to record the organisms present. Microscopical examinations of the water of the Elbe River have also been made. Much attention has been given to the careful enumeration of the different species, and, for the most part, the methods of the planktologists have been followed. The observations have shown that there is a regular seasonal succession of organisms which develop on the sand. During the winter the diatoms alone are represented, but certain species sometimes develop in great abundance. It is during the spring and fall, however, that the diatoms attain their maximum growth. The green algæ appear in the spring and increase during the summer. The blue-green algæ are present in large numbers during the late summer, their growth usually continuing until cold weather. Substantially, the same seasonal distribution was observed at Antwerp. It is interesting to note that it corresponds with the seasonal distribution of the microscopic organisms repeatedly observed in various lakes and reservoirs of this country.

At Antwerp similar studies of the surface scums have been systematically made, but somewhat different methods have been followed. The work has been carried on at the Waelham laboratory of the Antwerp Water-Works Company. Chief attention has been given to the dominant forms. The actual numbers of organisms present have not been

recorded, but the results have been expressed in proportionate parts of the total number present, on a scale of ten, as follows: Mr. Whipple.

Coscinodiscus	4½
Melosira	4
Cyclotella	1½
	10

On this date (Oct. 7th), therefore, the predominant forms were *Coscinodiscus* and *Melosira*. At another time the following genera were present:

Melosira varians	5
Fragilaria capucina	4
Spirogyra	1
	10

In this country similar results have sometimes been expressed in "number of organisms on 1 sq. cm. of sand." The following represents the results of a microscopical examination of the film at the top of an experimental sand filter. The sample was collected in March, after the filter had been in operation nearly two months:

	Number of organisms over 1 sq. cm. of sand. (In standard units.*)
Diatomaceæ:	
Asterionella	278 000
Cymbella	130 000
Diatoma	150 000
Melosira	10 000
Meridion	25 000
Navicula	7 700
Stephanodiscus	6 500
Synedra	1 100 000
Tabellaria	2 390 000
Chlorophyceæ:	
Closterium	1 200
Scenedesmus	800
Protococcus	60 500
Conferva	12 000
Spirogyra	5 500
Cyanophyceæ:	
Chroöcoccus	5 300
Oscillaria	84 000
Protozoa:	
Trachelomonas	16 000
Ciliata	5 000
Peridinium	4 000
Tintinnus	14 000
Mallomonas	800
Synura	6 000
Codonella	400
Rotifera:	
Anuræa	800
Polyarthra	1 000
Synchæta	8 000
Total organisms	4 324 500
Amorphous matter	2 300 000

* One standard unit equals 400 square microns.

Mr. Whipple. The organisms which develop over the surface of a sand filter may be grouped, for practical purposes, into three classes: those which form a matting upon the sand; those which are attached to the sand but extend upward in filaments or sheets; and those which are free-floating in the water. Perhaps it would be better to say that the organisms are found in these three conditions, because the same organism is sometimes found now on the sand and now above it.

The effects of these three groups of organisms upon the operation of the filter are not the same. The most important effect is that produced by those organisms which form a matting upon the sand. The diatoms and the unicellular algæ are here chiefly concerned. By their growth they form a more or less gelatinous film upon the surface, and as this film becomes denser, the rate of filtration is retarded until finally it becomes necessary to scrape the filter. The algæ which grow erect upon the sand do not thus clog the filter. On the contrary, they prevent clogging to some extent. Their waving, interlaced threads act as a sort of preliminary strainer, removing from the applied water some of the suspended matter which would otherwise collect on the sand. This action continues as long as the plants are in good condition and as long as the evolution of gas is sufficient to cause flotation. When they begin to decay or when they become overloaded with foreign matter they settle to the bottom and help to clog the filter. Kemna found that at Antwerp *Hydrodictyon* was the most effective organism in this process of preliminary straining. The free-floating forms have little influence on the rate of filtration as long as they remain in suspension, although, to some extent, they too play a part in the preliminary clarifying process. But ultimately most of them reach the surface of the sand and help to clog the filter.

Not only do the algæ growths over a sand filter affect the rate of filtration and the frequency of scraping, thereby increasing the cost of filtration; but they exercise an important influence upon the efficiency of the filter. It sometimes happens that the growth of the algæ is so vigorous and the evolution of gas so abundant that great masses of the organisms rise in the water, carrying with them patches of the surface film and leaving bald spots on the sand through which the water passes at too high a rate, with consequent loss of bacterial efficiency. At Antwerp the filter attendants watch for this phenomenon, and reduce the rate of filtration if necessary. It seems probable, also, that decomposition of the organisms at the surface affects the filtered water unfavorably.

During the course of the year the character of the flora changes. This change is often gradual, but at times is very rapid. Kemna has noticed that at the time when certain organisms are rapidly disappearing from the sand the efficiency of filtration is impaired. He attributes this to the changed condition of the surface film caused by

the decomposition of the organisms, but suggests that changes in the bacterial flora may also play an important part. In a recent publication* Dr. Ad. Kemna cites the following interesting experience with *Anabæna*: Mr. Whipple.

During the hot weather of July, 1899, *Anabæna* became abundant over some of the Antwerp filter beds. Knowing the character of this organism and its tendency to impart an odor to the water, he kept a careful watch of the filters, collecting samples of the filtered water twice a day and testing them as to their odor and the amount of ammonia they contained. As long as the *Anabæna* remained in a living condition in the water over the sand, the filtered water was satisfactory, but when the organisms disappeared, on the advent of cold weather, the filtered water acquired a bad taste and the amount of ammonia increased.

The studies made at Hamburg and at Antwerp show, with apparent conclusiveness, that when the vegetation over a sand filter is in a living condition, it is a positive aid to the efficiency of filtration, though it increases the cost of operation. Most of the microscopic organisms have a coating which is somewhat gelatinous, and in many cases the gelatinous material is very abundant. The diatoms and other organisms which grow directly on the sand aid in the formation of the surface film on which the efficiency of filtration largely, but not solely, depends. This fact has been understood for many years. The surface film forms through bacterial agency on covered filters as well as on open filters, but on the latter its formation is assisted by the microscopic organisms.

TABLE No. 8.—The Influence of Growing *Enteromorpha Intestinalis* upon Water Bacteria. (Direct Sunlight.)

Date.	Hour.	Temperature.	Number of Bacteria per Cubic Centimeter.	
			Culture of *Enteromorpha.*	Water without *Enteromorpha.*
July 6th	9 P. M.	18° Cent.	123	122
" 7th	5 A. M.	18° "	156	164
" 7th	9 A. M.	18.5° "	98	210
" 7th	3 P. M.	22° "	5	532
" 7th	7 P. M.	24° "	0	987
" 7th	9 P. M.	21° "	0	1 230

The experiments of Strohmeyer, at the laboratory of the Hamburg Water-Works, have shown that some algæ exercise a sterilizing influence upon the water in which they develop. *Enteromorpha*, for example, is a green alga which is often very abundant on the filter

*"Les Eaux Potables, Extrait de la Belgique Médicale."

Mr. Whipple.

beds during the summer. Strohmeyer selected and carefully cleaned some of the young, growing filaments of this organism and put them in flasks which contained about 300 c. c. of water, adding also 1.5 c. c. of a sterile culture solution. Other flasks of water were similarly prepared, but without the algæ. Pairs of these flasks, with and without the algæ, were subjected to similar conditions of light and temperature, and their bacterial contents determined at intervals of a few hours for several days. The result of one of these experiments is given in Table No. 8.

The figures show that at the beginning of the experiment the bacterial contents of the two flasks were practically the same. After standing for eight hours in the dark, the bacteria increased slightly in both flasks. After fourteen hours' exposure to direct sunlight, the water in the flask which contained the growing algæ was practically sterile, while in the other flask the development of the bacteria continued uninterruptedly. A similar experiment, carried on for a longer period in diffused light, gave the results shown in Table No. 9.

TABLE No. 9.—THE EFFECT OF GROWING *ENTEROMORPHA INTESTINALIS* UPON WATER BACTERIA. (Diffused Light.)

DATE.	HOUR.	TEMPERATURE.	NUMBER OF BACTERIA PER CUBIC CENTIMETER.	
			Culture of *Enteromorpha.*	Water without *Enteromorpha.*
July 4th	11.30 A. M.	18° Cent.	145	108
" 4th	2 P. M.	18° "	160	144
" 4th	6 P. M.	18° "	152	243
" 5th	8.30 A. M.	17° "	1 100	5 900
" 5th	2 P. M.	18° "	180	26 000
" 5th	6.30 P. M.	18° "	7	50 000
" 6th	9 A. M.	18° "	24	63 000
" 6th	7.30 P. M.	18.5° "	0	80 000

Here, the development of bacteria in the flask without the algæ was more vigorous than before, but the sterilizing action was less vigorous, as might be expected. Other experiments with *Spirogyra*, *Cladophora* and *Stichococcus* gave similar results. Whether the sterilizing action produced by the growth of the algæ was due to the effect of the gases liberated or to some other cause was not definitely determined.

What is true of these filamentous algæ is probably true of many other microscopic organisms, and, not only of the green algæ, but of the diatoms and, perhaps, the blue-green algæ. At the time when *Anabæna* was present on the Antwerp filters, Kemna observed that it was not equally abundant on all the beds, and that with the beds

where it was most abundant there was not only less clogging of the sand, but an increased degree of purification. Mr. Whipple.

The writer has had frequent occasion to observe the reduction of the number of bacteria in water by growths of microscopic organisms. The following case is very striking: A pond, with an area of 40 acres and a capacity of 42 000 000 galls., was affected with an immense growth of *Clathrocystis* which appeared in the spring and continued until the late autumn. At times the water contained 20 000 standard units of these organisms per cubic centimeter. The water that entered the pond was polluted, and the number of bacteria in it was seldom lower than 1 000 per cubic centimeter, and was often much higher. At the same time the number of bacteria in the water at the outlet of the pond was very low. On one occasion the following results were obtained, and these are typical of the conditions which prevailed for several months:

	Number of Bacteria per cubic centimeter.
Average of the influent streams	1 400
Average of samples throughout the pond	27
Sample at the outlet	36

A series of examinations of samples collected at the outlet of the pond during an entire year gave the following results:

	Number of bacteria per cubic centimeter.	Number of standard Units of *Clathrocystis* per cubic. centimeter.
January	.....	120
February	1 100	800
March	1 500	0
April	338	680
May	370	2 320
June	139	14 500
July	60	17 200
August	104	11 700
September	245	8 750
October	540	8 970
November	840	1 150
December	1 243	650

These figures show that the number of bacteria at the outlet of the pond varied inversely with the amount of *Clathrocystis* present. In this case a part of the reduction of the bacteria, at least, appeared to be due to a mechanical action by which the bacteria were engulfed in the mass of jelly in which the cells of *Clathrocystis* were embedded. Microscopical examination of the *Clathrocystis* showed that various kinds of bacteria were present in this gelatinous mass—micrococci,

Mr. Whipple. long bacilli, short bacilli, singly and in groups. The bacteria thus absorbed may or may not have been in a living condition, but at least they were incapable of developing on the gelatin plate. Microscopical examination of the cultures in the Petri dishes showed that in very few instances was a mass of *Clathrocystis* the nucleus of a colony of bacteria. Laboratory experiments were equally suggestive of the action of *Clathrocystis* on bacteria. A water which contained 430 bacteria per cubic centimeter was mixed with an equal volume of a water very rich in *Clathrocystis*, which contained but 39 bacteria per cubic centimeter, and shaken vigorously. Plate cultures of the mixed waters resulted in the development of only 60 bacteria per cubic centimeter. Other experiments of a similar character corroborated these results.

In the reservoirs of the Brooklyn Water-Works, it has been observed repeatedly that when *Asterionella*, *Synedra* and other organisms have been present in great abundance, the numbers of bacteria have been unusually low. There is some reason to believe that the microscopic animal growths tend to reduce the number of bacteria in water by consuming them as food. The relation between the water bacteria and the lower forms of microscopic plants and animals is certainly an intimate one, and the subject is one which deserves careful study, as it is not only important in connection with filtration, but has a direct bearing upon the self-purification of streams and other natural phenomena.

Mr. Rafter. GEORGE W. RAFTER, M. Am. Soc. C. E. (by letter).—This paper presents, in an interesting manner, the detail of a continuous filtration plant constructed substantially on lines followed for many years in England, and on the Continent of Europe generally. The cost of the plant per unit area is lower than that of the European plants, which is attributed to the favorable conditions at Albany. Basing his view on perhaps casual study of filtration plants abroad, the writer is, however, disposed to say that the decrease in cost is partly due, at any rate, to somewhat less elaborate construction than is common there. The extensive use of concrete has also contributed to keep the cost within moderate limits.

The author has referred to studies of the flow of the Upper Hudson, made by the writer. The cited figure of 1 647 cu. ft. per second, minimum flow, is probably not far from right, although in the summer of 1889, for a few days, the flow may have been as low as 1 200 to 1 300 cu. ft. per second.

Table No. 10 gives the run-off of the Hudson River in cubic feet per square mile per second, for a period of 12 years, from 1888 to 1899, inclusive. These figures do not represent the natural flow of the spring months, which are modified by a lumberman's storage of from 3 000 000 000 to 4 000 000 000 cu. ft. The Indian Lake Reservoir, of

4 470 000 000 cu. ft. content, was also brought into use in 1899, the storage therefrom being discharged into the stream during July, August and September. Had it not been for this large artificial inflow, the minimum of these months would have been considerably lower than shown. Mr. Rafter.

TABLE No. 10.—RUN-OFF OF HUDSON RIVER AT MECHANICSVILLE, FOR THE WATER YEARS, 1888 TO 1899, INCLUSIVE, IN CUBIC FEET PER SECOND PER SQUARE MILE OF CATCHMENT AREA.

(Catchment Area = 4 500 Square Miles).

Period.		1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899
Storage	December	1.78	2.22	2.93	0.72	1.91	0.90	1.60	0.97	2.42	1.54	3.05	1.22
	January	1.41	2.44	2.50	1.84	4.19	0.71	1.50	0.86	1.51	0.89	1.72	1.49
	February	0.82	0.84	1.76	2.58	2.06	1.07	1.08	0.79	1.04	0.87	1.50	1.17
	March	1.52	1.84	2.47	3.94	2.43	1.83	3.28	0.93	3.02	2.49	4.49	2.14
	April	4.73	3.04	3.34	4.44	4.79	3.98	2.47	5.31	5.55	4.24	3.07	5.25
	May	4.76	1.97	4.00	1.22	4.36	4.95	1.68	1.52	1.02	2.70	2.47	2.17
	Means	2.55	2.08	2.85	2.45	3.30	2.24	1.96	1.72	2.42	2.12	2.72	2.23
Growing	June	1.09	1.52	1.64	0.71	2.76	1.07	1.58	0.63	1.05	2.64	1.17	0.58
	July	0.34	1.28	0.43	0.52	2.08	0.56	0.70	0.50	0.62	2.39	0.57	0.54
	August	0.38	0.95	0.45	0.59	1.22	1.11	0.55	0.87	0.54	1.83	1.13	0.31
	Means	0.60	1.21	0.83	0.65	2.00	0.91	0.94	0.67	0.74	2.29	0.96	0.47
Replenishing	September	0.63	0.44	1.96	0.45	0.99	1.53	0.41	0.58	0.51	0.51	0.84	0.46
	October	1.02	0.83	2.04	0.33	0.63	0.86	0.81	0.58	0.91	0.56	1.75	0.58
	November	2.36	1.77	2.03	0.91	1.69	0.81	1.42	1.87	2.97	2.21	2.05	1.42
	Means	1.34	1.00	2.02	0.56	1.09	1.06	0.88	1.01	1.46	1.09	1.55	0.82
Water Year	Means	1.74	1.60	2.13	1.53	2.42	1.62	1.43	1.28	1.74	1.93	1.98	1.44

In his statements relating to cracks in the walls, the author apparently assumes that cracks in masonry are, on the whole, to be expected. This has always seemed to the writer so far an erroneous view that he is disposed to say that even in our severe winter climates, cracks in concrete masonry ought not to occur. At any rate, this general statement may be made for walls of any considerable thickness. For thin walls, the statement may possibly be modified somewhat, although there are certainly cases of such, of considerable length, free of cracks.

The writer is disposed to assign lack of cleanliness as a prolific source of so-called temperature cracks. As a general statement, for walls as long as those referred to by the author, the elasticity of the mortar ought to take care of expansion and contraction. But this implies thorough adhesion of the mortar. The chief remedy is, of course, cleanliness of stone and mortar materials.

By way of showing the elasticity of concrete under compression, reference may be made to the writer's studies of concrete as recorded in the Annual Report of the State Engineer and Surveyor of New

Mr. Rafter. York, for 1897, where tabulations of a large number of compression tests may be found. Without going into an extensive *résumé* of these tests, at this time, a few points may be cited in illustration of the writer's proposition.

Table No. 11 gives the serial number as per report to State Engineer, brand of cement, resilience and modulus of elasticity for a number of concrete blocks of 1 to 3 plastic mortar, 40% of the aggregate. The resilience here tabulated is for a gauged length of 5 ins., and a compression of 600 lbs. per square inch, while the modulus of elasticity is between loads of 100 and 600 lbs. per square inch.

TABLE No. 11.

Serial number.	Brand of cement.	Resilience for length of 5 ins.	Modulus of elasticity.
23	Genesee	0.0020	1 250 000
51	Wayland	0.0014	1 786 000
72	Iron Clad	0.0013	1 923 000
90	Empire	0.0011	2 273 000
109	Champion	0.0016	1 562 000
	Mean =	0.0015	.....

For a length of 1 ft., and with 600 lbs. per square inch compression, the mean resilience of the foregoing blocks is therefore found to be 0.0036 in. At this rate a concrete wall of the specified composition might be expected—if free to move—to expand nearly $1\frac{1}{2}$ ins. before serious consequences would result. Taking into account that so-called temperature cracks do not often exceed, even in walls several hundred feet in length, from $\frac{1}{8}$ to $\frac{1}{2}$ in., it has seemed probable to the writer that, with the proper precautions taken, they ought not to occur. At the same time, there is no intention of being specially insistent on these points, but rather to present them in the hope of eliciting further and, possibly, more profitable discussion.

For ordinary brick walls, the writer recognizes that they are very likely to crack under some of the conditions detailed in this paper.

Tables Nos. 11 to 16, inclusive, of the writer's report on Concrete, in the Annual Report of the State Engineer and Surveyor of New York, for 1897, give results of a large number of compression tests and computed moduli of elasticity for concrete and mortar. Additional data of this character may be found in the "Report on Tests of Metals and Other Materials, Watertown Arsenal, 1898." Indeed, recent compression tests have so multiplied as to enable one to form a fair idea of the elasticity of concrete and mortar. For other masonry materials there is still a great lack of data.

Mr. Christian.

G. L. CHRISTIAN, Assoc. M. Am. Soc. C. E. (by letter).—This paper is a valuable addition to the literature of water filtration. The large death rate from typhoid fever before the construction of the filter, and the material reduction in the deaths from that cause alone would justify the expenditure necessary for its installation. But, when all the inhabitants use the filtered water it would seem that the death rate should be decreased even more than it has been.

The writer was interested in the cracks in the concrete and brick masonry caused by the low temperature. He was also interested in Mr. Rafter's remarks on that subject, having had a similar experience some years ago while engaged on a reservoir in which there was a straight masonry wall approximately 475 ft. long. The height of this wall from the bottom of the reservoir to the under side of the coping was 26 ft. Its thickness was 4 ft. at the top and 13 ft. 6 ins. at the bottom.

It was built of second-class rubble masonry, the constituents being a freshly quarried gneiss of good quality and a mortar composed of 2 parts sand to 1 of a standard American Portland cement.

The rock was all cleaned and washed immediately before being laid, and the work was done by good masons, of experience in that line of work, and who were under constant supervision. The wall was completed during the latter part of August, and, as cold weather approached, it was examined carefully every few days.

Early in December the thermometer fell suddenly to 12° Fahr., and on that day cracks were noticed, as shown in Fig. 18. They extended

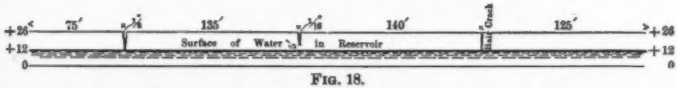


FIG. 18.

through the wall, were about at right angles to it, and generally followed the joints. They never widened, but, on the contrary, closed gradually as the water rose in the reservoir and the warm weather approached, finally closing so tightly that only by the closest scrutiny could they be seen, even though each place had been marked carefully in order that it might be found readily.

Mr. Trautwine.

JOHN C. TRAUTWINE, Jr., Assoc. Am. Soc. C. E. (by letter).—To the writer this paper has a special interest as a source of information and a basis of comparison, in connection with the several large plants now being designed for the filtration of the Philadelphia supply.

After innumerable reports upon filtration, by Councilmanic Committees, by local organizations,* by the writer, as Chief of the Bureau of Water, and by his predecessor, Mr. John L. Ogden, and after years of fruitless discussion and inaction, the present Mayor, Hon. Samuel H. Ashbridge, who took his seat on April 3d, 1899, secured from

* Including the Woman's Health Protective Association, which submitted a report by Mr. Jos. B. Rider and, later, one by Mr. Allen Hazen.

Mr. Trautwine. Councils, on April 20th, an ordinance providing for "the employment of three experts relative to the improvement, filtration and extension of the water supply," who were "to act in conjunction with the Director of the Department of Public Works, Chief of the Bureau of Water and Chief of the Bureau of Surveys in examining and reporting upon the question."

On May 8th, the Mayor announced the appointment of Messrs. Rudolph Hering, of New York; Samuel M. Gray, of Providence, and Joseph M. Wilson, of Philadelphia, Members, Am. Soc. C. E., who, on September 15th, presented a report recommending, in conclusion:

1. The adoption of that project by which the waters of the Schuylkill and Delaware Rivers, taken within the city limits, are purified by filtration.

2. The immediate improvement of the existing plant, in accordance with the detailed recommendations of their report.

Among the improvements recommended was the restriction of waste by the introduction of meters.

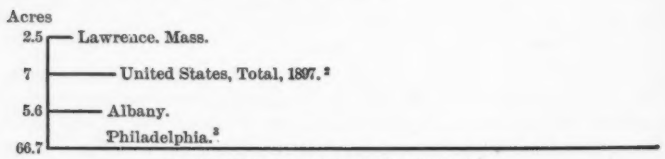
In their *résumé* and conclusions the experts say:

"We consider that, at present, a daily supply of 200 000 000 galls., being 150 galls. per capita, is a very liberal allowance. We recommend that this quantity of pure water be immediately provided for."

This involves a material restriction of the consumption, which is now variously estimated at from 220 000 000 to over 275 000 000 galls. daily.[1]

The striking features of the Albany plant are, perhaps, on the one hand, its immensity when compared with previously existing American slow filtration plants, and on the other hand, its insignificance (if the word may be used without offence), in comparison with the magnificent installation recommended by the experts for Philadelphia.

Prior to the construction of the Albany plant, with its aggregate filter-bed area of 5.6 acres, that at Lawrence, Mass., with a corresponding area of 2.5 acres was much the largest slow plant in America, and in 1897 the aggregate area of all those plants of which the writer could learn did not reach 7 acres (Fig. 19).[2]



COMPARISON OF AREAS OF FILTER BEDS.

FIG. 19.

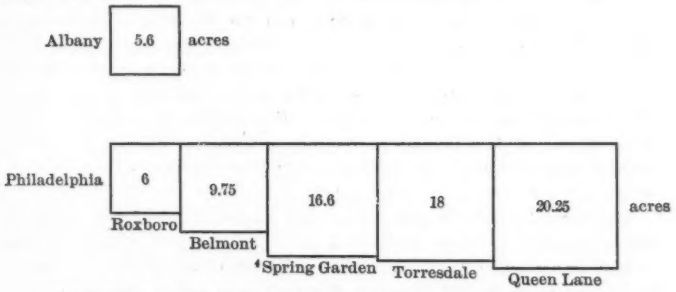
[1] Two hundred and twenty million U. S. galls., as estimated by the experts. By plunger displacement, after allowance for slip, the pumpage, as stated in Report of Water Bureau for 1898, was 275 000 000 galls.

[2] Mr. Hazen informs the writer that the aggregate area in the United States, in 1897, as then calculated by him, was a little over 9 acres. See *Journal* of the New England Water-Works Association, Vol. xii, p. 229.

[3] For a supply reduced to 200 million gallons per day, as recommended by the experts, at 3 million gallons per acre per day.

Upon visiting the Albany plant during its construction, in May, 1899, the writer was much impressed with the great extent of the operations in progress, indicated by the photographic views accompanying Mr. Hazen's paper, and it was therefore a startling reflection that these vast provisions would be insufficient to supply one of the four 20 000 000-gall. pumps at the Queen Lane (Philadelphia) pumping station, which station represents barely one-fifth of the aggregate nominal capacity of all the Philadelphia pumps, and that the daily pumpage at Philadelphia[1] was nearly fifteen times greater than the capacity of the Albany plant. Mr. Trautwine

Even with the restricted consumption contemplated by the experts, the Philadelphia filtration plant will be nearly, if not quite, the largest in the world, and certainly very much larger than any other under a single control.



COMPARISON OF AREAS OF FILTER BEDS, ALBANY AND PHILADELPHIA.
FIG. 20.

Philadelphia is supplied from six stations, the smallest of which (Roxborough) has a nominal daily capacity of 24 500 000 galls., and is credited, in the Bureau report for 1898, with an average daily pumpage of over 20 000 000 galls., as against 15 000 000 galls. nominal daily capacity, and 12 500 000 galls. actual consumption, for the Albany plant.

The aggregate bed area of the four slow plants recommended by the experts for immediate construction for Philadelphia is 54 acres, and, in addition to this, a rapid or "mechanical" plant of 50 000 000 galls. daily capacity was recommended for the Spring Garden System.

The filter-bed areas of these four plants, and the equivalent slow-bed area of the rapid plant recommended for the Spring Garden System[5] are shown graphically, and compared with that of the Albany plant, in Fig. 20.

[1] Two hundred and twenty million U. S. galls., as estimated by the experts. By plunger displacement, after allowance for slip, the pumpage, as stated in Report of Water Bureau for 1898, was 275 . 00 000 galls.

[4] "Rapid" plant, 50 000 000 galls. daily, taken as equivalent to $\frac{50}{3}$ = 16.6 acres of slow beds.

[5] Capacity allotted, 50 000 000 galls. per day. Rate assumed, 3 000 000 galls. per acre per day.

Mr. Trautwine.

The construction of the Albany plant happens most opportunely for the authorities in charge of the Philadelphia work, who may profit by it, not only as a pattern, but, if time permits, as a most useful monitor, showing where modifications may be advisable in the Philadelphia plants in order that they may be more perfectly adapted to the conditions there existing. Indeed, unless the differences in conditions between the two places are studied most carefully, the Albany plant will lose much of its special usefulness to the Philadelphia authorities.

Philadelphia draws more than 95% of its present enormous supply from five pumping stations on the Schuylkill River, whose water-shed is about 1 900 square miles, and the remainder, or less than 5%, from the Delaware, the water-shed of which, above Philadelphia, is between four and five times as large as that of the Schuylkill.

Between the Hudson, at Albany, and the Delaware, at Philadelphia, there is considerable analogy. Both cities draw from tide-water; each is within a half day of the sea, by water; in each case city sewers discharged into the river both above and below the intake prior to filtration; in each the design of the filtration plant involves the removal of the intake to a point above the discharge of city sewage; and the water-shed areas of the two rivers, above the two cities, respectively, are nearly equal.

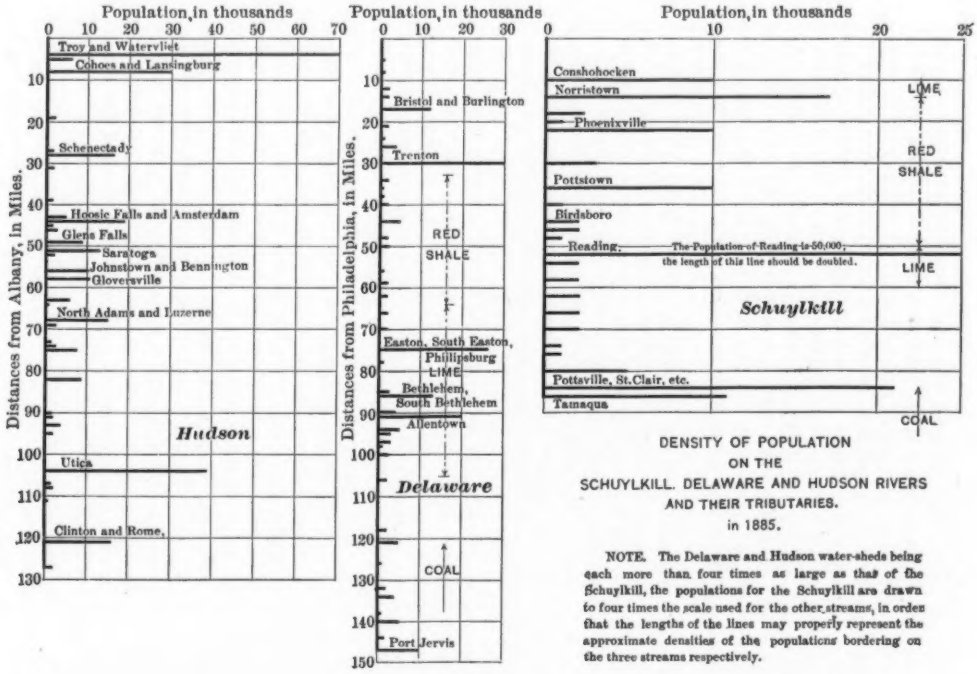
Mr. Hazen gives the population per square mile of the Hudson, above Albany, as 33 in 1880, and 43 in 1890, from which we may assume 38 as the corresponding figure for 1885;* while Mr. Hering, in his report on extension of water supply in 1885, gives the population of the water-shed of the Delaware, above Philadelphia, as 59 per square mile, including the Lehigh water-shed, and 54 exclusive of that water-shed.

The distribution of the population adjacent to the river, in each of the two water-sheds, is shown graphically in Fig. 21, in which they are compared also with that of the Schuylkill.

All the data of population shown in Fig. 21, are those for the year 1885, they having been found convenient of access in each case. While those of to-day would of course show a marked increase in most cases, yet the changes which have occurred are probably not of such a nature as to interfere with the usefulness of the figures given, for the immediate purpose in hand, viz., an exhibit of the relation between the three rivers in regard to density and distribution of population.

For the Schuylkill and Delaware the populations have been taken

*In his letter closing the discussion Mr. Hazen reminds the writer that these figures, for the Hudson embrace only the urban population, and states that the rural population is nearly constant at about 30 per square mile. This would make the total population, for the Hudson water-shed, in 1885, 68 per square mile, or about 15% greater than that of the entire Delaware water-shed, including that of the Lehigh, and 26% greater than that of the Delaware, exclusive of the Lehigh.



DENSITY OF POPULATION
ON THE
SCHUYLKILL, DELAWARE AND HUDSON RIVERS
AND THEIR TRIBUTARIES.
in 1885.

NOTE. The Delaware and Hudson water-sheds being each more than four times as large as that of the Schuylkill, the populations for the Schuylkill are drawn to four times the scale used for the other streams, in order that the lengths of the lines may properly represent the approximate densities of the populations bordering on the three streams respectively.

FIG. 21.

Mr. Trautwine.

from a map prepared by Mr. Rudolph Hering, and published with his report of 1885 on the improvement of the Philadelphia supply. In the case of the Hudson they were found by averaging the figures given by Mr. Hazen, in Table No. 1, for the years 1880 and 1890. The distances, for the Schuylkill and Delaware, were roughly scaled from the map mentioned. Those for the Hudson are given by Mr. Hazen in Table No. 1. In no case has the writer made any attempt at accuracy.

A striking feature, in the case of the Hudson, is the large population massed upon the banks of the stream at Troy and Watervliet, only 4 miles above Albany, with a further addition of population, half as great, within the next 4 miles, giving a total population (in 1885) of 100 000 within 8 miles of the intake. Nothing like this exists on the Delaware. The portion of Philadelphia lying above the intake has, in general, only a rural population, and the experts have recommended the removal of the intake to a point just within the upper city limit. The largest town on the Delaware (Trenton, N. J.) had, in 1885, a population of only about 30 000, or less than half of that of Troy and Watervliet, and it is 30 miles above the city. The entire population represented on the diagram as contiguous to the Delaware, within 50 miles of Philadelphia, does not equal that on the Hudson within 5 miles of Albany. Nevertheless, the density of population on the entire water-shed of the Delaware, as given by Mr. Hering, for 1885, is more than 50% greater than that for the Hudson, as deduced from Table No. 1.*

But while the conditions on the Hudson and the Delaware are thus seen to be somewhat analogous, a glaring contrast appears when we compare either of these two rivers with the Schuylkill; and, inasmuch as Philadelphia now takes more than 95% of her supply from the latter stream, and is to continue to take 75% from it, according to the plan recommended by the experts for immediate execution, the importance of bearing these differences in mind becomes at once apparent.

The water-sheds of the Delaware and the Hudson are each between four and five times as large as that of the Schuylkill, and the density of population is approximately in inverse proportion to the areas. On the map accompanying his report of 1885,† Mr. Hering states the average population of the Schuylkill water-shed above Philadelphia as 176 per square mile, while Mr. Dana C. Barber, in a table accompanying his report of 1884 upon his sanitary survey of the Schuylkill Valley,‡ gives the area as 1863.9 square miles, and the population as 372 000, making the average density of population 200 per square mile. In order to represent with approximate correctness the rela-

* See foot note * page 330.

† Report of Water Department, Philadelphia, for 1885.

‡ Report of Water Department, Philadelphia, for 1884.

tions between the three rivers in the matter of density of population, the writer has plotted the populations for the Schuylkill upon a scale four times as large as for the other two rivers. Mr. Trautwine.

Referring to the diagram of the Schuylkill, we find, within about 50 miles of the city, Conshohocken, Phœnixville, Pottstown and Birdsboro, all important iron manufacturing towns, and Norristown, a well-to-do county-seat, once important in the same respect, while, near the head-waters, are Pottsville and Tamaqua, both important anthracite coal mining centers.

Most of these towns are without sewerage systems. Reading is installing such a system, but, with commendable consideration for its neighbors down stream and in the absence of pressure from without, is also installing plants for the filtration of all the sewage led to the river.

Within the city limits of Philadelphia (and, therefore, not shown) and above all but the Roxborough station, is the important textile manufacturing suburb of Manayunk, with a population probably between 10 000 and 15 000. The sewage proper of Manayunk, including most of the discharges from the mills, all of which, until recently, went into the river, is now carried through an intercepting sewer, completed in 1888, to a point below the Fairmount dam, which separates the entire pumpage system from tide water, but much household and other filth is carried directly into the river by storm water, which is not admitted to the intercepting sewer; and probably much more (including, according to official reports, fæcal matter from dwellings of foreign laborers adjacent to the canal of the Schuylkill Navigation Company) is thrown into the canal, from which it passes into the river, barely a mile above the Queen Lane pumping station, the newest and finest of the city's water-works.

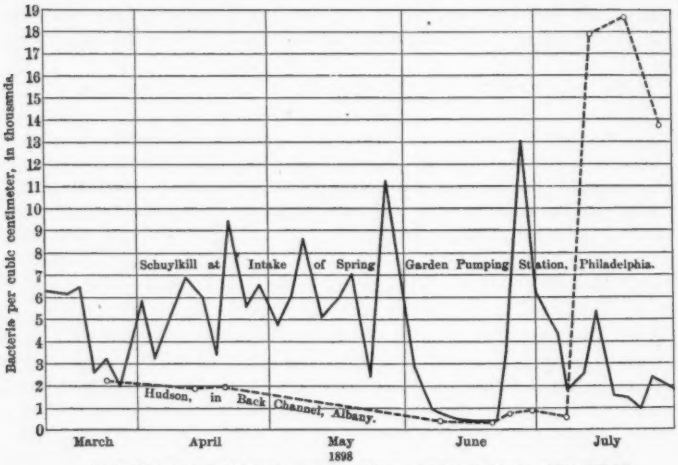
The canals of the Navigation Company, passing, as they do, through most of the towns along the river, and furnishing power to mills there, are naturally made the receptacles of offal, and the nuisance is especially flagrant beyond the city limits, where the city's Board of Health has no jurisdiction. A trip through the canal opposite Norristown, for instance, reveals great accumulations of filth of the most revolting description, scarcely awaiting the next rain to pass into the canal, and thence, in due course, into the river.

The Schuylkill, however, has this advantage over the Delaware and the Hudson, that the two pools, from which the pumps draw their supplies, are at least shut off from tide-water, and thus from the major part of the city's own sewage, by the dam at Fairmount.

Apart from sewage pollution, the Schuylkill suffers mineral pollutions of aggravated character.* In the anthracite regions, at and near

* See Fig. 21, in which the limits of the significant geological formations are indicated both for the Schuylkill and for the Delaware.

Mr. Trautwine. its source, it receives sulphuric acid, produced by the oxidation of the iron sulphide occurring in the coal, and large volumes of anthracite coal dust from the washeries, established during recent years for the purpose of extracting the small merchantable sizes from the culm or waste heaps which have been accumulating ever since the opening of the region, and from the "wet breakers," or breakers in which water is used for cleaning the coal and assorting it by sizes. The sulphuric acid is completely neutralized by the limestone of two extensive beds, one just above Reading and the other just above Philadelphia, and the water reaches the city with a basic or "hard" reaction.* The coal dust accumulates in the pools of the Navigation Company, but is swept out



BACTERIA IN SCHUYLKILL AND IN HUDSON RIVER WATERS, UNFILTERED.

FIG. 22.

and brought down to the city two or three times a year or oftener by floods.

Again, between Reading and Norristown, the Schuylkill passes a broad belt of easily decomposable red shale. In times of flood, this formation sends vast volumes of its substance, in suspension, into the stream, which, at such times, runs blood-red. The first effect of a general storm is, therefore, a visitation of red mud, which, a day or two later, is followed by water charged with coal dust. The writer has seen water drawn from faucets in Philadelphia, after storage in the city reservoirs, so black from coal dust as to be scarcely distinguishable from ink.

The Delaware (see Fig. 21) passes through practically the same

* The Delaware water, on the contrary, is quite soft, forming no scale in boilers.

formations, and receives its modicum of the same adulterants, but, owing to its much larger volume of flow, their effect upon the character of its water is much less marked. Mr. Trautwine.

Under the circumstances stated, it is not surprising that Fig. 22 shows a very much higher average number of bacteria in the Schuylkill water than in that of the Hudson (taken from Table No. 2), until after the "abnormal" conditions following July 9th set in, when the contractors on the Albany work "dumped sand and gravel in the back channel, and took it up again by dredging, for construction purposes, with the result that this water was fouled, and the samples taken after that time do not represent its normal condition."

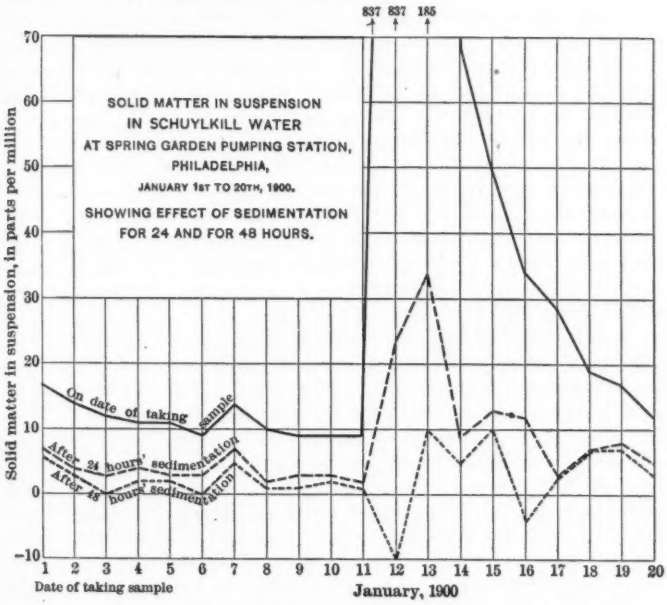

837 837 185
SOLID MATTER IN SUSPENSION
IN SCHUYLKILL WATER
AT SPRING GARDEN PUMPING STATION,
PHILADELPHIA,
JANUARY 1st TO 20TH, 1900.
SHOWING EFFECT OF SEDIMENTATION
FOR 24 AND FOR 48 HOURS.
Solid matter in suspension, in parts per million
On date of taking sample
After 24 hours' sedimentation
After 48 hours sedimentation
Date of taking sample
January, 1900

FIG. 23. (See page 336.)

Unfortunately, the writer is not in position to make a similar comparison between the two rivers in the matter of turbidity. During 1898 (the year for which Mr. Hazen's data in Table No. 2 are given), arrangements had not been completed for using the Hazen scale in observing turbidity in the Schuylkill, and the writer has not succeeded in deriving, from the examinations thus far recorded, a satisfactory coefficient for deducing the readings of the Hazen scale from the record, in parts per million, in which the Philadelphia results for

Mr. Trautwine.

1898 are stated. The Philadelphia results for March–July, 1899 (measured by the Hazen scale), do not differ greatly from the Hudson results as given by Mr. Hazen; but Mr. George I. Bailey, in his discussion, states that the highest turbidity reached since the filters were put in operation was 0.60; whereas, during the same period, it has on three occasions reached or exceeded that figure in the Schuylkill, as follows:

August 11th–12th, 1899	0.80
September 27th–29th, 1899	1.50 to 0.60
January 12th, 1900	0.90 to 1.50

In the course of the investigations of the experts, during the summer of 1899, sets of three samples each were taken daily from the Schuylkill and from the Delaware, and examined for (1) the total dry residue contained, (2) the amount of such residue deposited during the first 24 hours, and (3) the amount deposited during the first 48 hours. These observations are still being made, and the Schuylkill results for January 1st–20th, 1900, are indicated in Fig. 23, from which appears the startling result that in some cases the amount deposited exceeded the amount originally contained in the water. In others (not shown), the results indicated that less sediment was deposited in 48 than in 24 hours. These erratic results are due, no doubt, to differences in the samples, although these were taken at approximately one and the same hour and place.

Notwithstanding that these investigations indicate in many cases a very nearly complete deposition of all the sediment during the first 24, or at furthest during the first 48, hours, the water, as a matter of fact, often remains visibly turbid for many days thereafter.

Fig. 24 shows a comparison between the Schuylkill and the Delaware as to total solids in suspension during three periods of flood, from which it appears, as might have been expected, that in the smaller stream this effect of floods is not only much more marked and generally of shorter duration, but also appears and disappears earlier than in the larger stream. During normal stages, the sediment in both rivers ranges ordinarily between 10 and 30 parts per million.

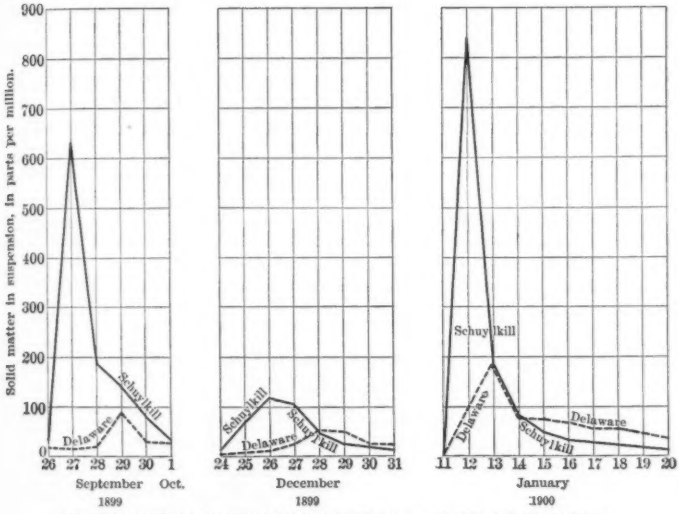
These comparisons show that the Schuylkill filters at Philadelphia will not only have a heavier bacterial duty to perform than those at Albany, owing to the greater number of bacteria, but will also be handicapped by the heavier doses of sediment in its water.

So far as the writer knows, there are on record no data which enable us to judge of the effect, upon the efficiency of the filters, of the coal dust brought down the Schuylkill and Delaware Rivers at times from the anthracite coal regions.

In the writer's judgment, the conditions stated render advisable a high degree of caution in using the construction and operation of the

Albany plant as a precedent in the design of the vastly larger system required for the filtration of the quantities of water taken daily from the Schuylkill for the supply of Philadelphia. In taking leave of the city service in November last, the writer addressed to the Mayor a communication, urging (as in many previous communications) that one or two of the smaller plants be built first, and "that the construction of filtration plants for the rest of our supply shall proceed as rapidly as we acquire, from the two initial plants to be immediately constructed, the knowledge so essential for such an undertaking." It is therefore gratifying to find his Honor quoted as saying recently that, after the

Mr. Trautwine.



SOLID MATTER IN SUSPENSION IN SCHUYLKILL AND DELAWARE WATERS AT PHILADELPHIA, IN TIMES OF FLOOD.

FIG. 24.

plans are completed, which will be "when thorough tests have been made at the new testing station," "it will then be in order to invite proposals for the work of constructing filtration plants at one or more of the city's stations."

With regard to that large portion of its supply which is drawn from the Schuylkill, Philadelphia is fortunate in having at her disposal the large reservoirs heretofore used for storage of the water after pumping, and incidentally for a very imperfect improvement in quality by means of sedimentation. In a report dated February 16th, 1898, to the Director of the Department of Public Works, the writer suggested that the reservoirs be utilized as sedimentation basins, a small portion

Mr. Trautwine.

of their total capacity being set apart for the storage of filtered water, and this feature was an essential one in a system of filtration suggested by the writer on September 9th, 1898, as well as in that recommended by the experts in their report of September 15th, 1899.

As regards the small portion of its supply taken from the Delaware, Philadelphia, like Albany, is without reservoir capacity of a kind which could be utilized conveniently for sedimentation of the water as a preliminary to filtration. Of the two small reservoirs of that supply, the one which has sufficient elevation is small and defective, and has but one basin. Both the experts' and the writer's proposed systems therefore provide for the construction of sedimentation basins for the Delaware supply.

An attempt to compare the cost of construction of the Albany plant, as given by Mr. Hazen in Table No. 3 and in his accompanying remarks, with that of the four proposed slow beds for Philadelphia, as estimated by the experts, is complicated by the difficulty of placing the two systems, with any certainty, upon one and the same basis of comparison. Mr. Hazen says, regarding the Albany plant:

"The filters, sedimentation basin and pure-water reservoir are connected in such a way as to make an exact separation of their costs impossible; but, approximately, the sedimentation basin cost $60 000, the pure-water reservoir $9 000, and the filters $255 000."

This makes the cost of the sedimentation basin about 18½% of the whole.

TABLE No. 12.—Cost of Filter Beds and Appurtenances at Albany.
(See page 340.)

(*a*) Items common to filters, pure-water reservoir and sedimentation basin.		(*b*) Items proper to filter beds and pure-water reservoir.	
		Brought forward,	$125 254.59
Preliminary draining.	$1 956.71	Gravel for lining.....	1 508.75
Excavation	21 761.64	Stone for lining.....	1 850.74
Embankment	8 340.80	Concrete in vaulting..	29 999 20
Filling.....	3 360.00	Brick work	35 603.75
" rolled	3 960.00	Filter gravel.....	7 645.05
Puddle	8 973.25	Filter sand	36 100.00
Concrete in floors....	27 112.47	Vitrified pipe.....	7 153.32
Other concrete.....	6 703.11	Manhole covers.....	2 956.80
Cement.....	61 368.52	Sand-run fixtures....	3 260.00
Extra work and minor items.....	10 150.11	Regulator houses....	6 897.92
		Fence	1 704.00
	$153 686.61		$259 934.12
81½ per cent.....	$125 254.59	Deduct cost of pure-water reservoir.....	9 000.00
			$250 934.12

Mr. Trautwine.

TABLE No. 13.—Estimated Cost of Slow Filter Beds and Appurtenances, for Philadelphia. Deduced from Report of Experts. (See page 340.)

Plant.	Belmont.		Roxborough.		Queen Lane.		Torresdale.		Total.	
Capacity, in United States gallons per day.	27 000 000.		15 000 000.		58 000 000.		50 000 000.		150 000 000.	
Clearing	$9 000	.....	$8 000	.....	$10 000	.....	$10 000	.....	$37 000	.....
Excavation	31 200	.....	19 249	.....	66 382	.....	55 383	.....	172 214	.....
Sand washers*	3 200	.....	2 200	.....	7 200	.....	5 600	.....	18 200	.....
Drains	1 530	.....	1 130	.....	7 390	.....	6 060	.....	16 110	.....
Beds	490 568	.....	303 697	.....	1 009 949	.....	904 236	.....	2 708 450	.....
Fence	15 000	Add 15%†	10 800	Add 15%†	15 600	Add 15%†	5 000	Add 15%†	46 400	Add 15%†
Total	$550 498	$633 073	$345 076	$396 838	$1 116 521	$1 283 999	$986 279	$1 134 221	$2 998 374	$3 448 129
Per million gallons daily	20 389	23 447	23 005	26 456	19 250	22 138	19 725	22 684	19 989	22 987
Excess over Albany ($16 729).	22%	40%	38%	58%	15%	32%	18%	36%	19½%	37%

* Including "piping to sand washers." † 15% added by experts, presumably to cover "engineering and contingencies."

Mr Trautwine.

Taking the items under "Filters, Sedimentation Basin and Pure-Water Reservoir," in Table No. 3, separating those supposed to be proper to the filter beds and the pure-water reservoir from those common also to the sedimentation basin, using only 81½% of the cost of the latter items, omitting items not included in the Philadelphia experts' estimates, as quoted in Table No. 13, and, finally, deducting $9 000 as the cost of the pure-water reservoir, we arrive at the estimate of the cost of the Albany filter beds, given in Table No. 12, or, taking the capacity at 15 000 000 galls. per day, $16 729 per million gallons of daily capacity.

For the four slow plants, at Philadelphia, we have the figures in Table No. 13.

The figures for Philadelphia, in Table No. 13, include excavation for a pure-water basin for Belmont and for Torresdale, and for a sedimentation basin at the latter station, but, from the contours of the sites it would appear that the major portion of the excavation, in each case, was for the filter beds proper. Besides, in the case of the Albany plant, no doubt much more than the 81½% which we have taken for excavation is chargeable to the sedimentation basin.

Much of the very considerable difference between the cost at Albany and the estimates of the experts for Philadelphia may, no doubt, be explained by the advance in prices between the execution of the Albany contracts and the making of the Philadelphia estimates; but, after making all allowances, it would appear that the experts' estimates, at least after their addition of 15%, are certainly safe.

Table No. 14 is a comparison of the total cost of improvement.

TABLE No. 14.—Comparison of the Total Cost of Improvement.

	Philadelphia (estimated).		Albany (actual).
	(*a*)	(*b*)	
Population assumed	1 333 333	1 333 333	95 000
Average daily consumption, in gallons per capita	150	75	158
Total gallons	200 000 000	100 000 000	15 000 000
Cost of installation:			
Land	$1 120 353	$100 000	$8 290
Filter plants, piping, sedimentation basins and accessories	6 818 468	3 235 000	323 960
Pumping stations	1 514 770	56 500	49 745
Mains	1 520 000	432 000	86 638
	$10 973 591	$3 823 500	$468 633
Waste restriction	100 000	1 000 000	0
Additions to and improvement of existing plant	3 290 500	1 107 000	0
Engineering and contingencies	Included.	Included.	28 000
Total	$14 364 091	$5 930 500	$496 633
Per million gallons daily	$71 820	$59 305	$33 109

Mr. Trautwine.

Of the two estimates given for Philadelphia, (*a*) is that of the experts, taken from pages 107, 122 and 123 of their report, and (*b*) is based upon a report by the writer, made September 9th, 1898, to the Director of the Department of Public Works, in response to a resolution of Councils. In order to make estimate (*b*) properly comparable with the other two, it has been amended by adding 50% to the estimated cost of the filters, to provide for their roofing, and an item of $700 000 to provide for roofing the clear-water reservoirs.

The resolution requesting this estimate asked for "plans and drawings and estimated cost of filtration of all the water used by the city," and the writer took advantage of the word "used," to show the city fathers what could be done, in the way of proper economy, by restricting the consumption to a figure (maximum 100 galls. per capita per day), more nearly commensurate with the quantity (possibly 50 galls. per day, maximum) really used.* The estimate was based upon the Albany bids, which then had just been opened, and the amounts of which were kindly communicated to the writer by Mr. Hazen for the purpose of the estimate.

The figures indicate an economy out of proportion to the proposed reduction of consumption, but this was to be expected. For the smaller quantity, sites were generally available on city property adjoining or near to existing plants, whereas, for the larger quantity, sites for the filter beds had, in all cases, to be acquired. In other ways, also, and notably in the matter of mains to connect existing works with filter beds perforce located at considerable distance, the total cost, in Philadelphia, increases much more rapidly than the quantity to be filtered.

Philadelphia lies just south of the line which Mr. Hazen has drawn to indicate at what locations it is advisable to roof over the filter beds, and the question of the advisability of doing so for Philadelphia may be one for experts to discuss. Poughkeepsie, after some twenty years' experience with an uncovered bed, built another, and the writer, largely on the strength of this, omitted roofing, in designing for Philadelphia the system already mentioned, but he has since been informed that the building of a second uncovered filter bed at Poughkeepsie was contrary to the advice of Mr. Fowler, the Superintendent.

As to cost of operation, the experts make estimate for Philadelphia, as follows:

"Per million gallons of filtered water, including labor, cost of wash and waste water, lost sand, sanitary analyses of water, chemicals, superintendence, watchmen, ordinary repairs, and all incidental expenses; but excluding interest, depreciation and cost of pumping water to filters:

	Schuylkill River.	Delaware River.
Slow filters.....	$3.60	$3.00
Rapid filters.....	4.80	4.00

* The result was a resolution, by the Water Committee, requesting the Department "to place in proper form the results of its researches on the question of Slow Sand Filtration for the entire city."

Mr Trautwine. "Cost of pumping, per million gallons raised 1 ft. high, including coal, labor, oil, waste and supplies, and ordinary repairs; but excluding interest and depreciation:

"Low-Lift Pumps.

"For a daily supply of 200 000 000 galls., 5.25 cents."

In his report of September 15th, 1898, the writer, with much misgiving, due to insufficiency of data, ventured an estimate of $3.97 per million gallons as the cost of slow filtration proper, and $0.41 per million gallons as the cost of raising the water by low-lift pumps, making a total of $4.38.

Considerable research, including a correspondence with all the American filtration plants of which the writer could learn, developed costs of filtration alone, ranging all the way from $1.50 to $10 per million gallons filtered, the latter figure represented by Lawrence, Mass., and the writer concluded that:

"In the absence of more exact information, and in view of the excessive turbidity of our water in flood and of the rate of wages fixed by ordinance of Councils for an 8-hour day's labor, it would be unsafe to estimate the cost of operation (exclusive of interest on cost), for the filters contemplated, at less than $3 per million gallons, notwithstanding the large dimensions of the proposed works, which should conduce to economy, and notwithstanding that the proposed reduction in consumption would greatly facilitate sedimentation. On the other hand, with proper economy, the cost should not exceed $5."

Mr. Bailey's experience with the Albany filters, as deduced from their operation from September 5th to December 25th, 1899, inclusive, and stated in his discussion, shows a cost, for filtration proper and laboratory work, of $1.67, and $2.52 for raising the water from the river to the sedimentation basin, making the total cost $4.19 per million gallons.

Mr. Soper. GEORGE A. SOPER, C. E. (by letter).—In the discussion of this valuable paper which has thus far been printed, attention seems to have been centered mainly upon the design and construction of the filters, a direction which was naturally suggested by the title of the paper itself. The fact that the question of purifying the Hudson River water for the City of Albany involves a great deal more than the mere design of filter-beds, with their piping and other fixtures, however, seems to warrant a more general survey of the matter.

At the outset, the problem, as stated by the author, was the purification of a water which was very heavily polluted with sewage and was believed to have contributed greatly to a high typhoid-fever death rate. The author says that, previous to his connection with the case, investigations relative to methods of purifying the supply had been made, and that the plan which he formulated, when the matter came before him, was based partly upon data which had been thus obtained. Briefly stated, it was recommended that a new intake be built, and that a settling basin and filters be constructed to treat the

water. Strictly speaking, the complete scheme included, also, a new pumping station, a system of aeration, a clear-water conduit and provision for storing the filtered water. Mr. Soper.

The storage of the filtered water has already taken up some space in the discussion, and the possibility that the clear water may develop organisms under the present circumstances, has been pointed out. In order to throw more light upon the subject, it is hoped that the author will supply information concerning the relative proportions of filtered and raw surface waters which will be stored together in the open reservoir, and the approximate length of time during which the mixture will remain exposed to the sun.

The purification plant was to consist of two parts: A settling basin and filters, and, as a means of obtaining a favorable quality of water, to begin with, the intake was to be placed in a side channel of the river. It is to be observed that the aim was to produce a water of unobjectionable quality, and that in the general scheme, two important measures, besides filtration, were to be taken to secure pure water. Filtration was to be used to complete bacterial removal, but the water was first to be obtained in as pure a state as possible, and then modified in a manner which would be favorable to that process. The weight and character of the suspended matter which is found in the Hudson River water, normally and after storms, has not been stated, and we are not informed as to the degree of modification which was considered necessary. Yet it would appear that these were matters of prime importance in influencing the choice of a design.

Keeping in mind the fact that not comparative purity, but a quality of water which would agree with high standards of bacterial purity, was demanded, it must be stated that the final product of the plant does not appear to be wholly satisfactory. The author has informed us, in the first appendix of his valuable book on filtration,* what it is reasonable to expect a filter to produce. According to the rules of the German Board of Health, the number of bacteria in the effluent of a filter treating surface water, should not exceed 100 per cubic centimeter. The data thus far supplied show that the Albany average exceeds this figure, and that for the first month the number of bacteria in the effluent was more than twice, and for the last month nearly twice, that required by the German standard. On occasions, which have been frequent enough to attract notice, the bacteria in the effluent have exceeded 500 per cubic centimeter.

It is a curious fact, but one based upon considerable observation, that the efficiency of a filter, as stated in terms of percentage of removal, is commonly understood to be a definite indication of the quality of the effluent. This is a mistake, since a 99% removal,

* "The Filtration of Public Water Supplies."

Mr. Soper. although showing that a large proportion of the impurities have been removed, gives no indication whatever as to the amount of pollution which remains. Yet, as has been pointed out, it is the pollution which remains in the effluent which is of importance. To quote an illustration, and to apply this reasoning to the present case, the Albany filters have shown for four months, according to the Superintendent's figures, a reduction in bacteria of 99%, while the average number of bacteria left in the water was 168 per cubic centimeter. This excludes the figures for the first week, which do not appear to represent a normal operation. An examination of the tables shows that there have usually been upwards of 200 bacteria in the effluent when the numbers in the raw water have exceeded about 13 000.

The importance which attaches to the foregoing remarks has a general application, and leads to a query as to the number of bacteria which we may consider it good practice to allow upon a filter of this type. Obviously, there should be a limit, if the effluent is to be narrowly controlled. If the quality of the final product of a purification plant is to be fixed at a standard of, say, not over 200 bacteria per cubic centimeter, and the effici ency of a filter is to be estimated at 98 to 99%, it will be necessary to modify the quality of the water which is to be supplied to the filter, so that the number of bacteria which reaches it shall not be above 10 000. This should offer no serious engineering difficulty.

In regard to the color and odor which are not removed by filtration at Albany, it would seem that the chosen position of the intake may account, in part, at least, for the trouble. The "back channel" receives the drainage of the municipal gas-works, the waste accumulations which result from the sand-washing operations of the filters, and, not improbably, diluted sewage from Albany, which is carried up by the action of the flood tides.

It would seem that the original plan of an intake in the main channel of the Hudson was more favorable, from every point of view except that which takes into account the normal turbidity of the Hudson River water. Had it been found expedient to place the new intake in the main channel, and to provide added facilities for sedimentation or chemical precipitation, there seems to be no doubt that the operation of the filters would have been more uniform, and the quality of the effluent more satisfactory as regards bacteria, color and odor.

These are a few of the points which have been considered by the writer, after a review of the information which has been supplied. It is hoped that more information concerning the preliminary studies of the raw water will be forthcoming, and that additional data concerning the efficiency of the plant will justify its design and support the very high opinion with which the work is now regarded.

ALLEN HAZEN, M. Am. Soc. C. E. (by letter).—The discussion has brought out a large number of practical points, both in reference to the Albany plant and to filtration in general Mr. Hazen.

The results of operation given by Mr. Bailey are most gratifying, and the cost of operation, as exhibited in the comparison made by Dr. Mason, is very favorable, and shows an excellent organization of the work.

The water quantities given by Mr. Bailey are taken directly from the filter records. Some preliminary experiments have indicated that the coefficient of discharge assumed in computing the orifices was too small by about 5%, and that this amount should be added to the results. The value of the coefficient of discharge seems to be almost exactly the same whether the orifice is submerged or not. It is the intention to make more precise determinations, and afterward to have new and correct scales painted and substituted for those now in use.

Since the presentation of the paper a flood has occurred higher than any on record except that of 1857, which was a little higher. No damage was caused, but when the water exceeded the height of the overflow in the sedimentation basin, the river water entered it in that way. One of the pumps was kept in operation at a low rate to keep the pumping station dry. The operation of the filters was not interrupted or interfered with in any way.

In discussing the vaulting, Mr. Hill has made certain computations of quantities, and in doing so he has, apparently, divided the total amounts of concrete in the vaulting and in the flooring by the number of bays. In doing this, the writer thinks, he has overlooked the number of bays in the pure-water reservoir, and has also overlooked the fact that nearly half of the concrete in the floors was in the sedimentation basin and had nothing to do with the filters. He has also omitted the cost of the cement.

The figures for one section, 13 ft. 8 ins. square, corrected, and adding the price of the cement, are approximately as follows:

As executed:

5.4 cu. yds. of vaulting, at $6.30	$34.02
4.85 cu. yds. of flooring, at $4.75	23.04
1.24 cu. yds. of brick work, at $9.67	11.99
	$69.05

As proposed:

10 cu. yds. of roof slab, supporting column, floor and foundation, at $4.75	$47.50
Centering, 4 cents per square foot	7.47
Expanded metal	10.60
	$65.57

The 5.4 cu. yds. of concrete vaulting, per section, given above, includes the proportionate part of all special structures, and of the excess weight of the cylindrical vaulting near and over the walls.

Mr. Hazen. Without these, but including the manholes, the actual amount of concrete was only 5.1 cu. yds. per section.

The exact form of construction suggested by Mr. Hill was not considered, but several others of the same general type were studied before the plans were put in final shape. Some of these methods appeared very promising. The cheapening, however, depended upon a reduction of the thickness of concrete to less than 6 ins. While good results might no doubt have been obtained with concrete 3 or 4 ins. thick, reinforced with steel, there was no known precedent for its use under similar conditions. The Water Board was unalterably opposed to the use of any form of construction which could be regarded as in any degree experimental, and for this reason it was decided to use only types of construction which were well demonstrated. It was therefore necessary to postpone until another time a practical trial of the steel and concrete construction.

It would have been better to have covered the whole of the vaulting with a thin layer of sand before placing the silt and soil, and, particularly, to have surrounded the manholes with gravel. The draining would have been facilitated by this procedure, and the lifting of the manholes by frost would have been made impossible.

The estimate of the cost of vaulting per square foot, given by Mr. William B. Fuller, is a little greater than that given by the writer, recently, in discussing Mr. Metcalf's paper.* The difference arises from, first, the fact that Mr. Fuller has reckoned the cost of the vaulting upon the net filtering area, while the writer reckoned it upon the whole area covered; and, second, the fact that Mr. Fuller has included in the cost of the vaulting the cost of that part of the floor which he assumes to be due to its use as a foundation. The cost of vaulting, of course, is much the largest element of difference between the costs of open and covered filters, but it should be remembered that there are other points of difference, and that deducting the cost of vaulting from the cost of covered filters does not necessarily give the cost of open filters. Correct comparisons can only be made by examining corresponding designs for filters of the two types, using the same unit prices.

Mr. William B. Fuller and Mr. Fowler have suggested that covered filters have other advantages than protection against frost which may make their construction desirable, even in climates where covers are not necessary to prevent ice. This may sometimes be the case, but it should be borne in mind that, aside from the question of ice, there are distinct advantages and disadvantages arising from the use of covers. The writer does not propose to discuss this question at length; but, to show that this opinion is not unanimous, he will state that Dr. Strohmeyer, after making the extended investigations mentioned in Mr.

* *Transactions*, Am. Soc. C. E., Vol. xliii, p. 63.

Whipple's discussion, states that he has come to the conclusion that open filters have decided advantages over covered ones, quite aside from considerations of difference in cost. Mr. Trautwine also raises this question. Of course, in severe climates there is no question as to the necessity of covering filters. It is only where the winters are not too severe that the question arises. Mr. Hazen.

The sufficiency of the vaulting as a protection against cold has been tested during the past winter. Ice has formed to a thickness of 3 or 4 ins. immediately about the entrances to the filters, but it has been found possible to break up this ice and let it pass through the gates leading to the overflow chambers as the water is drawn from the filters before cleaning. Over the rest of the filters a skim of ice has formed occasionally, but this could be thrown aside during cleaning, and has not seriously interfered with the work.

Mr. Rafter is right in stating that the writer assumed that, on the whole, cracks are to be expected. It is a matter of common experience that small masonry structures remain entirely free from cracks. As the size of the structure increases, particularly if the masonry is comparatively light, the probability of cracks increases. It should be remembered that temperature contraction is only one of the causes of cracks in masonry. Cracks often occur through settlement, and at Albany six cracks were caused by the lifting of the walls by frost, due to the exposure of some of the work in an uncompleted condition. When a crack has once occurred it is not an easy matter to repair it so that the wall will be as strong as it was originally, and it then makes little difference whether it was caused originally by settlement, temperature or other causes.

When the plans were being drawn, the question of the bearing power of the foundations was considered quite seriously. The site was a soft marsh. Borings showed a hard material at a comparatively slight depth over the greater part of the area. When test pits were dug, a clay was found fairly hard as first exposed, but shrinking considerably on drying, and, if disturbed in contact with water, becoming very soft. Experiments were made by loading 1 sq. ft. of this material, and some settlements were observed. A part of the filters was to rest upon this foundation, a part upon rock, and a small part upon still softer clay. It was expected that there might be settlement in parts of the work. With this in view, an attempt was made, first, to distribute the weight over as large an area as possible, thereby reducing the probability of settlement; second, to load the whole foundation as evenly as possible, so that in case settlement occurred the whole structure would go down together, with the minimum damage; and, third, the possibility of settlement and of cracks was contemplated in designing all parts of the structures, and the endeavor was made to arrange the masonry so that it would suffer as little as possible in case

Mr. Hazen. of settlement. Provision for cutting off water coming through cracks was also made, as described in the paper.

When the excavation was made, the foundation proved to be much better than we had felt safe to assume from the character of the borings and test pits; and the fact that no measurable settlement occurred on any part of the filters must be attributed rather to the natural excellence of the foundations than to the design. In the pumping station some settlement actually took place, but the cracks resulting from it have not proved serious.

The cross-walls were built of brick instead of concrete, principally because the writer supposed that brick would be less likely to crack than concrete; and also because he believed that in case it did crack, the cracks could be repaired more easily. The writer's more recent experience with concrete, in this respect, has been quite favorable; and in a smaller plant, since designed and built, at West Superior, Wis., all the walls are of concrete. The bonding in these concrete walls was made as described in the paper, and the writer believes that in this way the joints between the old and new work are made substantially as strong as any part of the work. When cracks occurred at Albany, they went straight through the walls, and did not follow any of these joints.

To build masonry structures without cracks is certainly desirable. The writer believes, however, that a much larger proportion of the inferior work performed by filtration plants than is generally supposed has resulted from cracks in the masonry structures; and until the art of masonry construction is so far advanced as to make it quite certain that structures can be built without cracks, it is justifiable and necessary in designing filters, to consider the probable effect of cracks, and to take precautions against the damage which might result from them. Such precautions can be made entirely effective, and at a comparatively small expense. The writer believes that the design at Albany is such that, had there been many more cracks, or had there been some little settlement in portions of the work, the structures would still have maintained their stability, and would have continued to serve the purpose for which they were built.

In reply to Mr. Maignen's question, the sand-washing apparatus is not protected from the weather, and no sand is washed during the winter months. The dirty sand during this time is piled up in the court to be washed in the spring. It would, no doubt, be possible to protect the apparatus so as to wash in winter, but there is no objection to allowing the sand to remain until spring.

In regard to the thickness of the gravel layers, mentioned by Mr. Fowler and Mr. G. W. Fuller, the writer has constructed and observed many filters during the last dozen years, many of them experimental, and a smaller number for actual work. In many cases he has used gravel layers thinner than those at Albany. He does not remember

that he has ever used thicker layers in the aggregate, although in some cases the minimum over the tops of the drains may have been a little greater. He has had occasion to examine quite a number of the drains after they had been in use for considerable periods, and in no case has he been led to think that thicker gravel layers would have been desirable. Thin gravel layers, of the right sizes and carefully placed, are, in his opinion, quite as good as thicker ones. Much thicker layers, carelessly placed, or not of the right sizes, are entirely inadequate. It is cheaper and better in every way to use comparatively thin layers, and to take the trouble to make them right, and have them effective, than to use thicker layers and depend to a certain extent upon chance for the results. Mr. Hazen.

The methods adopted by the contractors at Albany for screening and placing the gravel were particularly satisfactory. There has not been the slightest evidence of incomplete support, nor does the writer consider that there is any danger that the sand will get into the gravel so as to injure the filters.

In this connection, it may be stated that the coarse gravel over the drains, and particularly about the joints, was placed with unusual care. The workmen were instructed personally in the methods to be adopted in this part of the work. They quickly became skilful at it, and were faithful in carrying out their instructions.

Mr. Fowler mentions the clogging of the holes in the inlet pipes to the sedimentation basin. In practice, it is found that these holes are stopped up, to a certain extent. The appearance of the outlets is not very much changed until a considerable proportion of the holes is stopped. Practically, the rate of pumping always exceeds the capacity of the holes, and water is always flowing over the tops of the pipes. It is necessary to clean the holes at intervals, and this is done with a broom, by a man in a boat. The cleaning is done very quickly. It can be done at any time when the pumps are stopped, or, when they are running, by shutting off the inlets in rotation. The inlets have actually been cleaned at intervals of a week or two, and the labor required was very slight.

At another time, the writer would put the inlets somewhat farther away from the bank. With this done, it would be possible to leave the perforated pipes in position during the winter. As it is, the spray from them builds ice upon the bank. They were actually taken off soon after the commencement of cold weather. This is not a very important matter as they are easily taken off; there is probably no necessity for aeration during the winter, and, with the lower lift, a little coal is saved.

The question raised by Mr. Fowler as to the size of individual filters and the number of beds in a plant, is an important one. It should be remembered, however, that while the convenience of operation is generally increased by increasing the number of beds, the cost of construction per unit of area is also increased, and it may often be

Mr. Hazen. found best to sacrifice something of present convenience to economy of construction ; or, in other words, with a given sum of money, to build a larger area of large beds, rather than a smaller area of small ones.

The comparisons of populations upon several rivers, mentioned by Mr. Trautwine, are extremely interesting. It should be noted, however, that the figures given by the writer for the Hudson River include only the populations of cities, towns and villages, and, as stated in the paper, do not include the rural population. The rural population, obtained by going over the water-shed by counties, and deducting the populations of cities, towns and villages given in the table, amounts to about 30 per square mile, for 1890. The rural population does not change rapidly, and a close approximation to the total population at the various dates would be obtained by adding 30 per square mile to the figures for the urban population given in the table.

The methods of distribution of the cost of various parts of the plant, given by Mr. Trautwine, are not entirely clear to the writer. The figures given in the paper were obtained by going over each item somewhat carefully, and allotting the proper proportion to the structures indicated. The final results were given in round numbers, because of the impossibility of deciding the exact points of division between the various parts mentioned.

The question raised by Mr. G. W. Fuller, as to the quality of the raw water, has been already answered in part by Mr. Bailey in his discussion. Data upon these points are rapidly being accumulated at the laboratory of the works, and much more complete results will be available after a little while. The data at hand at the time of the preparation of the paper were so meager in comparison with those now being obtained, that it was thought best to let the matter stand until it could be discussed more adequately.

The general character of the water, as regards muddiness, is between the very clear waters of most New England streams, and the turbid waters of the Middle States, although it resembles the former more than the latter. Generally, the raw water is comparatively clear, but very muddy water is obtained occasionally, especially from the Mohawk, which drains a clayey country from which the water is quite muddy. The fluctuations in turbidity are much less rapid at Albany than in some other places, and when the water becomes turbid it remains so for several days. The greatest turbidity yet observed is such that a bright platinum wire 0.04 in. in diameter can be seen through only 1 in. of water.

In reply to Mr. Whipple's question, Bleecker Reservoir, which is perhaps the most important of the distributing reservoirs, has recently been thoroughly cleaned. The laboratory in connection with the filter plant will make studies of the vegetable growths which occur in the reservoirs, but it is too early to draw any conclusions upon this point.

Mr. Hazen.

The odor due to gas waste, mentioned by Dr. Mason, first occurred after the paper was prepared. The odor was offensive on only one occasion during the fall, resulting from a combination of extremely low water, spring tides, and a south wind. Dr. Mason has indicated the proper solution of this problem, and the gas company has made arrangements to build a drain to the Patroons Creek sewer, so that this material, instead of being discharged into the back channel, will be discharged into the river below the southern end of the island, where the opportunities for dilution will be much greater. It is also to be hoped that improved methods at the gas-works will reduce the amount of this highly objectionable material to be discharged into the river. It should be understood that this odor was due to material discharged into the back channel at a point near the intake, and carried up to it in a comparatively concentrated condition, and not to material which had become mixed with a considerable portion of water flowing in the river.

In reply to Mr. Soper's questions, the Prospect Hill or high-service reservoir, holding 7 500 000 galls., receives filtered water only, and its capacity is such that the water remains in it probably from one to two days. The Bleecker or middle-service reservoir, holding 30 000 000 galls., receives water by gravity from Rensselaer Lake in varying quantity, according to the supply, and the balance is filtered water. The relative proportions of the two supplies vary widely at different times. The Tivoli or low-service reservoir, holding 19 000 000 galls., is generally supplied by gravity, but water is let down to it from Bleecker reservoir whenever the supply falls short.

Regarding the standard of bacterial purity mentioned, as given in the rules of the German Board of Health, it should be remembered, in the first place, that this standard was purely provisional, and in the second place, that the number of bacteria is determined by growing on plates at a temperature of 20° Cent. for 48 hours. The writer is informed that current American bacteriological practice requires the growth of the plates for a considerably longer period than this, and that studies as to the best composition of the nutrient gelatine, etc., have resulted in the adoption of a procedure by American bacteriologists which gives much higher numbers than the German procedure.

It should be further noted that the bacterial efficiency of a filter is generally low at starting, and increases with use; and it is to be confidently expected that the bacterial efficiency of the filters will be greater during the coming year than that indicated by the figures given by Mr. Bailey.

Mr. Soper speaks of the removal of the bacteria by sedimentation. The writer believes that the improvement of water in this manner depends almost entirely upon the character of the sediment carried by it. Many western streams carry much sediment, to which the bacteria are

Mr. Hazen. apparently attached, and when the sediment goes to the bottom the number of bacteria in the water may be greatly reduced. The Hudson River water at Albany generally carries but little sediment, and holding the water for 24 hours in the sedimentation basin does not diminish materially the number of bacteria in it. It is the writer's opinion that, for the conditions at Albany, about 24 hours represents the economical limit of subsidence, and that no improvement in the water, commensurate with the increased cost, would be obtained by detaining it for a longer period.

Regarding other methods of preliminary treatment, it is undoubtedly true that the color could be removed by the addition of from 1 to 1½ grains of sulphate of alumina per gallon, and the alkalinity of the river water is probably such that this amount could be used without injurious results. It is believed that the present plant contains all the appliances necessary for the application of this procedure, except the tanks for dissolving the chemical; but it is not thought that the advantages to be obtained would be commensurate with the cost, and with the possible danger from the use at times of excessive amounts of coagulant. It should be noted further that it does not necessarily follow that the same percentage of bacterial efficiency will be obtained by filtering a water from which many of the organisms have been removed by preliminary processes. The contrary has sometimes been observed, when the filtration of a partially purified water has given effluents no better than could be obtained by a similar filtration of the raw water.

Regarding the position of the intake, the back channel has received the drainage of the gas-works, and the dirty water from the sand washing. Arrangements have been made to remove the discharge from the gas-works to a point below the back channel. None of the city sewers discharges into the back channel, the outlet farthest up stream being the Patroons Creek sewer, which enters the river a short distance below the lower end of the island. The writer believes that it is not true that much less turbid water is obtained from the back channel. At low-water stages the turbidity is substantially the same at all points. At flood stages the dike is overtopped, and the waters in each channel are identical. The advantage of the back channel consists, not in the sedimentation which takes place in it, but in the greater time required for the sewage-polluted water to reach the intake. This delay allows some of the bacteria to die, and it is in this way that the better bacterial condition of the water is to be accounted for.

The relative characters of the waters in the back and main channels are observed at frequent intervals, and when the construction of the intake to the main channel comes up again, very much more full and satisfactory data will be at hand as to the character of the water which could be secured from it.